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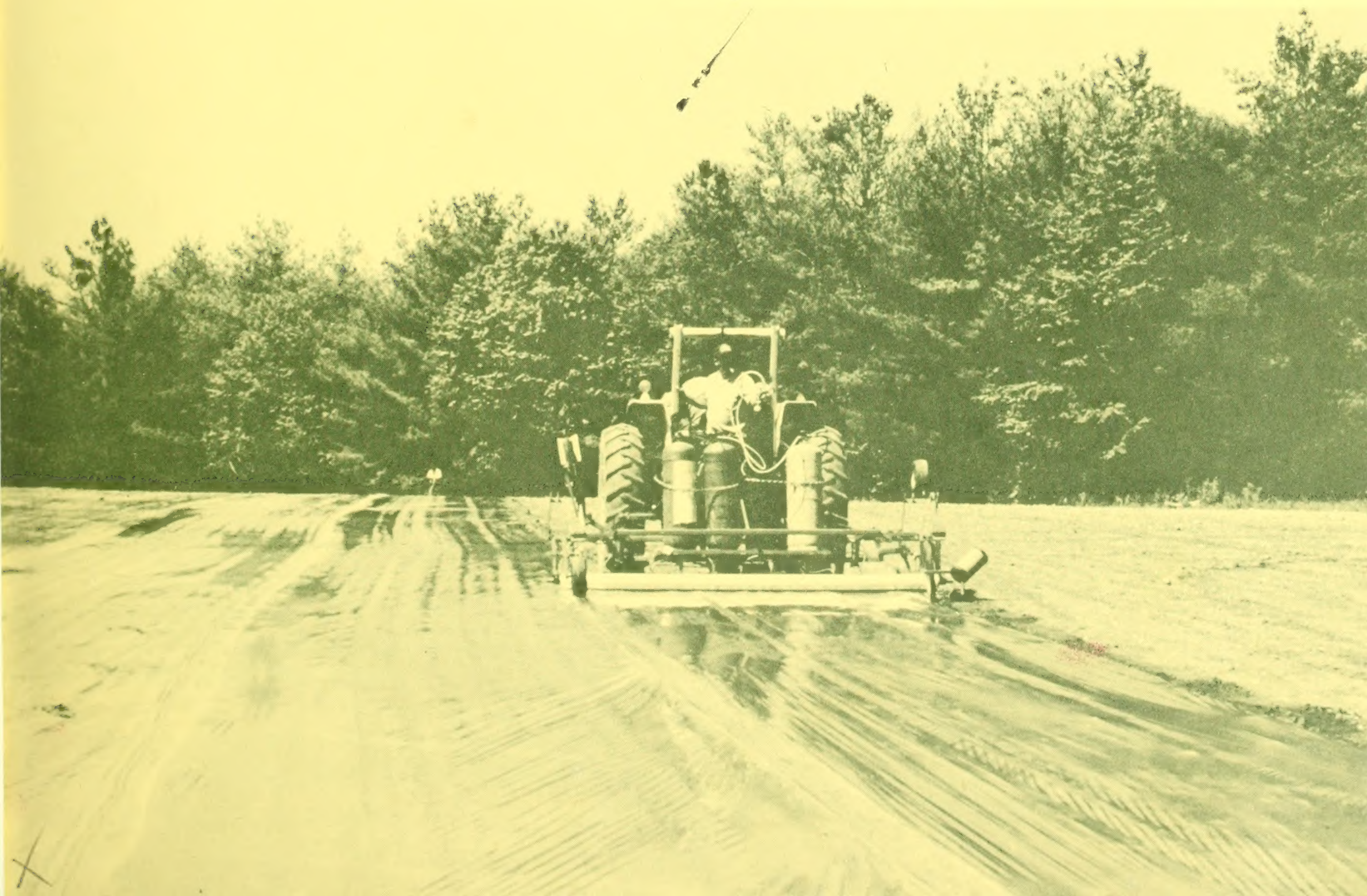
August 14-18, 1989
Bismarck, North Dakota



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Abstract

This proceedings is a compilation of 23 articles on various aspects of forest nursery management in western North America. In addition to general nursery technical reports, special sections are devoted to fumigation in forest nurseries and articles pertaining to Great Plains nurseries. A summary of past meetings and content of Proceedings for the years 1960-1988 is included.

Note

As part of the planning for this symposium, we decided to process and deliver these proceedings to the potential user as quickly as possible. To do this, we asked each author to assume full responsibility for submitting reviewed manuscripts in photoready format within tight deadlines. Thus, the manuscripts did not receive conventional Forest Service editorial processing, and consequently, you may find some typographical errors and slight differences in format. We feel quick publication of the proceedings is an essential part of the symposium concept and far outweighs these relatively minor distractions. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations or the USDA-Forest Service. Trade names are used for the information and convenience of the reader, and do not imply endorsement or preferential treatment by the sponsoring organizations or the USDA-Forest Service.

On the cover: Soil fumigation with methyl bromide/chloropicrin using the continuous tarp method (photo from Cordell 1989 — in this Proceedings)

USDA Forest Service
General Technical Report RM-184

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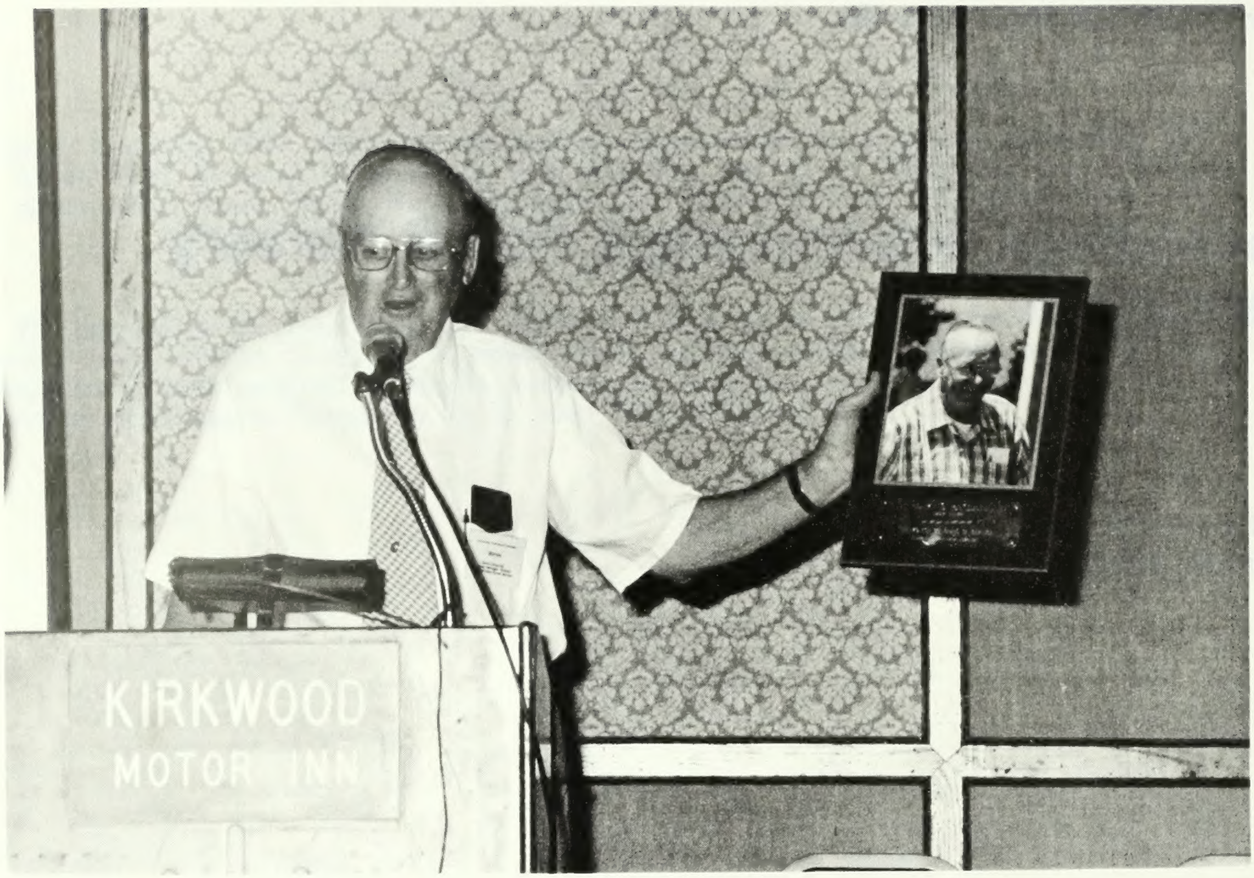

Retired Colorado State Nursery manager Marvin D. Strachan was honored for his 30 years of service to the Intermountain Forest Nursery Association. The award was presented by Lee W. Hinds, past manager of Lincoln-Oakes Nurseries and long-time member of the Association. Marv was one of the organizers of the first meeting in 1960, when he was manager of the Big Sioux Conifer Nursery in Watertown, SD.

Contents


JOSEPH H. STOECKELER
ARBORETUM

Intermountain Nursery Association: An Historical Account of 30 Years' Progress — 1960-1989[1]

Marvin D. Strachan[2]

Abstract.--This paper reports on the 30-year history of the Intermountain Nursery Association. The persons active in organizing the Association as well as those active and responsible for important progress through the years are noted. The difference in discussion topics between 30 years ago and now are also noted. The importance and progress in technology transfer is pointed out. A condensed review of all previous meetings has been prepared and is included as an appendage to the 1989 proceedings.

It is a pleasure and an honor for me to speak to you today pertaining to the historical aspects of the Intermountain Nursery Association. There are less than 250 forest nurseries producing tree planting stock for conservation/reforestation use in the United States and I have found that nurserymen are some of the most sincere and dedicated people I have known. You are my kind of people.

The Intermountain Nursery Association originated in 1960, at a time when most of the state and federal nurseries in the region were either new or had experienced major expansion as a result of the USDA Soil Bank programs. Agricultural leaders throughout the nation felt that trees planted on agricultural Soil Bank acres would permanently take cropland acres out of production and relieve national agricultural surpluses. A corresponding shortage of adaptable tree planting stock was recognized and the various states were encouraged to establish nurseries to produce the tree planting stock necessary to plant the cropland acres taken out of production. Federal USDA funds were made available for nursery establishment and expansion.

The nurseries so affected were developed very rapidly. Suitable nursery sites had to be located, soils and water had to be tested for optimum seedling production capabilities, irrigation water supply developed, and funds obligated for facilities, equipment, and all supplies necessary to produce and distribute seedling trees during the fiscal year fund allocation.

Most of the new nurseries were developed or expanded on lands previously occupied by agricultural crops and far removed from forest soil conditions. Problems developed early on with soil conditions, climate, soil/species adaptation, lack of technique and technology and adequate production funding. Most of the new nurserymen, with limited nursery experience, were looking to the Lake States, West Coast, and Southeast regions for technology transfer to assist in their local problems. Formation of the Intermountain Nurserymen's Association was a welcome experience to these nurserymen.

Leadership in the initial stages was provided by encouragement from the Intermountain State Foresters and through the efforts of Marv Strachan and Wally Wheeler, Division of State & Private Forestry, USFS, Denver, in calling the nurserymen in the region together for organizational purposes. The Association started with a small number of nurseries represented but grew annually with the addition of nurseries in North Dakota, the prairie provinces of Canada, the reforestation nurseries in Montana and Idaho and representatives from Kansas, Oklahoma, Texas, New Mexico, Arizona and Nevada. Research and Administrative representa-

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[1]Paper presented at the Intermountain Nursery Association annual meeting, Bismarck, ND, August 14-18, 1989.

[2]Marvin D. Strachan is retired Nursery Manager, Colorado State Forest Service, Fort Collins, CO and a former Nursery Manager and founder of the Big Sioux Nursery, Watertown, SD.

tives from the various state and federal agencies enhanced a much broader perspective of nursery operations.

An even broader scope of nursery production, equipment use, seedling handling and nursery management was attained through the efforts of Homer "Red" Ward, Washington State Department of Natural Resources. His encouragement and invitations for the Intermountain Nurserymen to meet jointly with the Western Forest Nursery Council began in 1964 and continued in 1967, 1968, and 1969. The first joint meeting was held at the Coeur d'Alene nursery in 1970. The joint merger of the two nursery organizations was proposed several times but in each case the merger was rejected by vote of the organizations. Each organization wished to maintain separate nursery associations but would meet jointly whenever possible. The Intermountain Nursery Association meets every other year during even dated years. The Intermountain Nurserymen meet jointly with the Western Forest Nursery Council during the even dated years.

Further assistance to the Intermountain Nursery Association was provided in 1978 with the selection of Steve McDonald, USFS, as a Westwide Nursery Specialist. Tom Landis followed in this position in 1981. The nursery specialist not only enhanced nursery technology transfer between nurseries in the region and provided liaison within the nursery industry but also assisted in annual meeting program development, compilation of papers and funding for printing of the proceedings of the Intermountain Nursery Association annual meetings beginning in 1980.

During the 1985 annual meeting, the membership voted to change the name of the Intermountain Nurserymen's Association to the present name of <u>INTERMOUNTAIN NURSERY ASSOCIATION</u>.

A review of the past proceedings provide many memorable thoughts of the many experiences and progress of the association. Not only has the nursery association provided the opportunity for nurserymen to visit and learn from nurseries in most states in the western half of the country but also have provided for special events. Some of these special events have been:

(1) The North American Containerized Forest Tree Symposium held in Denver, Colorado in 1974. This symposium brought together many nurserymen, foresters and scientists throughout the United States, Canada and many foreign countries to learn of the state-of-the-art in containerized seedling production.

(2) The tour of containerized nurseries in Oregon in 1978 for Intermountain Nurserymen sponsored and hosted by the USFS through efforts of Steve McDonald and Frank Ter Bush. This happened at a time when several of the Intermountain nurseries were very new in containerized production or were contemplating entering into this mode of production.

(3) The North American Forest Tree Nursery Soil Management Workshop in Syracuse, New York in 1980. This workshop brought together nurserymen from throughout the United States and Canada to learn more of nursery soil management. Such special events have been of great value to the nurserymen and were made possible through your association.

One of the most important things that has happened within the Intermountain Nursery Association during the past 30 years is the advance in technology. This evidence is dramatic when examining the proceedings for the past three years. Such topics as:

(1) Computer vision for grading seedlings

(2) Field performance of mini-plug transplants

(3) Root growth potential as an indicator of outplanting performance

(4) Superabsorbent hydrogels and their beneficial long-term opportunities

(5) Nursery crop management computer system

(6) Cumulative trauma disorders in forest nursery workers

(7) Monitoring cold hardiness of tree seedlings by infrared thermography

(8) Bedhouse seedling production

(9) Irrigation according to PMS and tensiometer instruments.

These things were never heard of, or not used, 30 years ago. However, the more things change, the more they stay the same as evidenced by topics in the past three years' proceedings. Some problems seem to be continuous items for discussion since the beginning of time as follows:

(1) Nursery practices/seedling sizes/field performance

(2) Effect of nursery culture on morphological and physiological development of seedlings

(3) Impact of lifting date and storage on field performance

(4) A stock quality assessment procedure for characterizing nursery grown seedlings

(5) Effects of nursery density on pine seedlings

(6) Fall lifting--its effects on dormancy intensity of ponderosa pine seedlings

(7) Weed control--alternatives to herbicides

(8) Some effects of cold storage on seedling physiology

(9) Fumigation effect on soil-borne pathogens, mycorrhizae, and growth of seedlings

(10) Soil compaction--effects on seedling growth

(11) Herbicides for conifers--what's new?

(12) When to measure seedling quality in bareroot nurseries

(13) Soil mapping and testing

(14) Organic matter--how much is enough?

(15) Should private nurseries produce seedlings for federal/state reforestation programs?

One topic that seems to tell most of the story was found in the proceedings of the 28th meeting in 1988. The topic was entitled "Fixing the Edsel: Can Bareroot Stock Quality be Improved?" It seems that as long as we have forest nurserymen they will press for more technology and better application to grow a better tree.

Thank you ladies and gentlemen for inviting me here today to review the past 30 years of progress in the Intermountain Nursery Association.

Importance of Species and Seed Source Selection in Great Plains Nurseries[1]

Richard A. Cunningham[2]

Abstract.--Increased tree planting, resulting from federal programs and tree planting promotions, has increased the transfer of planting stock among Great Plains states. These transfers increase the probability that poorly-adapted planting stock may be planted. Nursery managers and tree planters are cautioned to use only seed source-identified planting stock. Local seed sources are recommended unless appropriate provenance tests support the use of specific non-local seed sources.

INTRODUCTION

Tree planting in the Great Plains, and in the United States as a whole, has greatly increased in the past five years (USDA 1988). This trend has been driven by several factors. Tree planting has been promoted by The Conservation Reserve Program (CRP), the Centennial tree planting programs in North Dakota and South Dakota, Soil Conservation Districts, the American Forestry Association's Global Releaf program, and the National Arbor Day Foundation. The increased tree planting emphasis developed quickly in the last two years and has left little lead time for nurseries to gear up their production to meet the increased demand for planting stock. Nursery managers are well aware that increased seedling production requires increased seed procurement several years in advance of need for the planting stock. The rapid increase in the demand for planting stock has outstripped the capacity of many nurseries to produce it and shortages of some species have occurred.

In order to avoid shortages, tree planters and nursery managers may attempt to procure stock from non-traditional sources such as public nurseries in other states, or from private nurseries in the same, or other states. Purchasing planting stock from non-traditional sources increases the probability that poorly-adapted seedlings will be planted. This can be the result of several factors:

1) private nursery staff may be uninformed about importance of seed source;
2) out-of-state nurseries may not have appropriate seed sources;
3) tree planting contractors may accept non-adapted stock just to get something to plant;
4) seedlings may be repackaged and lose identity;
5) some planting stock may pass through several vendor's hands with a resulting loss of information at each transaction.

THE PROBLEM

Whenever seed or seedlings are moved to a region where they have not been tested, an element of risk is involved because their performance potential is unknown. They may perform very well, or very poorly. Poor adaptation may result in poor survival, slow growth, damage or losses from insects, diseases, drought and cold. Unfortunately, these impacts may take several years to become evident. In addition, it may be difficult to separate the causes of these impacts. Poor performance may be the result of any combination of the following factors:

1) poor physiological condition of nursery stock;
2) poor planting techniques;
3) poor maintenance practices; or
4) genetically non-adapted or poorly-adapted seed sources.

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[1] Paper presented at the Intermountain Forest Nursery Association Annual Meeting. [Bismarck, N.D., August 14-18, 1989].

[2] Richard A. Cunningham is a Research Geneticist, USDA-Agricultural Research Service, Mandan, N.D.

There are several examples of the use of poorly-adapted seed sources in the Great Plains. Siberian elm was planted extensively throughout the Great Plains during the 1920's and 1930's. Several different seed sources had been planted but no trials comparing seed sources had been established. Early autumn freezes that occurred in 1938 and 1942 and the extremely cold winter of 1942 were followed by widespread die-back and mortality of Siberian elm throughout the Great Plains (George 1944, Webb 1948, Maxon 1951). Siberian elm trees grown from unknown seed sources or southern seed sources suffered losses 75-90 percent greater than northern seed sources from the Harbin area of China or farther north.

Many provenance tests have been established in the Great Plains and nearly all of them contain dramatic examples of non-adapted, or poorly-adapted seed sources. The ponderosa pine provenance study established by the Rocky Mountain Forest and Range Experiment Station in 1968 included test sites throughout the Great Plains. The results after 15 years of growth in those tests have been reported by Van Haverbeke (1986). Table 1 shows results from the plantations at Watertown, South Dakota and Hastings, Nebraska. The north-central Nebraska race performed the best at both sites. The percentage loss in survival and total height of five other races is compared to the north-central Nebraska seed source. These results could be interpreted as demonstrating that if one of the five other races were planted at either Watertown or Hastings, their performance would be inferior to that available by planting the north-central Nebraska race. The percentage loss values estimate how inferior those races would be.

Clonal tests of vegetatively propagated species also provide good examples of poorly-adapted clones. Table 2 compares the performance of six Populus clones five years after planting in central North Dakota. The hybrid clone Populus Xeuramericana (14271) performed best in terms of total height, lack of crown die-back and fewer terminal shoots. If any of the other clones are planted in central North Dakota, they can be expected to be inferior to clone #14271 to the extent shown in the percent loss columns.

SOLUTIONS

There are several strategies that can be utilized to reduce the use of poorly adapted seed sources. They range from simple and low cost to complex and costly. The most elementary of these strategies is to always use seed sources of known origin. Knowledge of seed source origin is critical for documenting performance, either bad or good. Performance records can then be linked to individual seed sources, and will serve as valuable bases for deciding whether to use that seed source again in the future.

Table 1. Relative performance of ponderosa pine races at two locations in the Great Plains.

Watertown, South Dakota

RACE	SURV	Loss[1]	HT	Loss[1]
	- - (%)	- -	(ft)	(%)
Southern	18	81	5.5	65
Northwest	38	60	8.7	45
Central Rocky Mtn.	70	26	10.2	35
Foothills-Black Hills	75	20	12.0	24
N. High Plains	92	3	13.9	12
N.C. Nebraska	95	0	15.8	0

Hastings, Nebraska

RACE	SURV	Loss[1]	HT	Loss[1]
	- - (%)	- -	(ft)	(%)
Northwest	56	44	9.8	42
Central Rocky Mtn.	99	1	10.3	39
Southern	85	15	10.9	36
Foothills-Black Hills	99	1	11.9	30
N. High Plains	98	2	13.1	22
N.C. Nebraska	100	0	16.9	0

[1]Percent loss compared to north-central Nebraska race.

Knowledge of the geographic location of the trees from which the seed was harvested gives you some information about the potential adaptation of those trees to your planting site. If the trees are native to the area, they are likely well adapted in terms of survival. If the trees are planted and their origin is unknown, their performance may provide an acceptable demonstration of their adaptation, particularly if they are at least one-half the normal rotation age for that species and intended use. If seed sources of known origin are not available, it is better to postpone planting for a year rather than risk the problems of planting ill-adapted stock. Remember, a landowner has to live with his, or your, choice of planting stock for the life of the plantation. If he chooses not to live with poorly performing planting stock, then he must bear the expense of removing them and starting over again.

Table 2. Relative performance of Populus clones at Mandan, North Dakota.

CLONE	MORT[1]	LOSS[2]	TERM[3]	LOSS	HT	LOSS
	- - %	- -	(no)	(%)	(ft)	(%)
NE-259	74.0	74	4.2	162	11.7	29
Nor'Easter (NE-237)	34.5	34	3.6	125	14.6	14
Northwest Poplar	2.0	2	1.4	+12	12.7	23
Siouxland	2.5	3	4.6	188	15.5	7
Imperial Poplar	3.0	3	3.5	119	15.7	6
Euramericana (14271)	0	0	1.6	0	16.7	0

[1]MORT = percentage of the crown that is dead.

[2]Percentage loss compared to Euramericana (14271) clone.

[3]TERM = the number of terminal shoots in the top one-third of crown.

Fortunately many state forestry agencies have recognized the importance of using planting stock grown from well-adapted seed sources. One state, Arkansas, has even gone so far as to adopt a policy that prohibits the planting of Atlantic coastal seed sources of loblolly pine in Arkansas if the plantings are to be cost-shared by that agency. Acceptable, local seed sources are identified on a map of Arkansas. This policy was prompted by the poor survival and growth of Atlantic coastal sources in some plantations that had been planted by forest industries 20 years previously.

The second strategy to use in a sound seed procurement program is to use local seed sources whenever possible, unless you have reliable information documenting specific non-local seed sources that may perform better than your local seed sources. Populations of native species will have become adapted to the local environment through the process of natural selection. They should survive well and perform satisfactorily. If the results of provenance tests have identified superior non-local seed sources, then they should be used if available. However, don't try to "stretch" the area of adaptation too far. If your planting site differs significantly from the site upon which the provenance test was conducted, the results may not apply to your site. Seed zoning systems can provide guidelines useful in determining whether a particular seed source can be considered "local" for a particular planting site (Cunningham, 1975). Seed may not be available from local seed sources as a result of poor seed years. It is a good practice to build up an inventory of seed in "good" seed years, to help carry you through the "bad" seed years.

Another strategy to consider in seed procurement is the use of seed from seed increase blocks or seed production areas. These areas can provide reliable sources of large quantities of seed that have the potential for genetic superiority. Seed production areas can be relatively inexpensive to establish and can be managed for increased seed production. Phenotypic selection can be followed by roguing to eliminate undesirable trees. Good performance through at least one-half the rotation age usually is a reliable predictor of performance at maturity. Planting stock grown from the seed harvested in seed production areas can be monitored to provide performance records and document seed sources of known performance potential.

One of the most intensive, and costly seed procurement strategies, is the use of seed from seed orchards. Seed orchards are normally developed only for high priority species. They are expensive to establish and maintain and usually require many years before they produce useful quantities of seed. The advantage they offer is the high level of genetic superiority their progeny should possess, particularly if the trees in the orchard have been progeny tested and the orchard has been subsequently rogued of poor performing clones. Even untested seed orchards generally have a high potential for genetic superiority and are usually superior to other available seed sources.

Genetically superior clones of vegetatively propagated species can be quickly integrated into the production programs of most nurseries. Cuttings from superior clones can be established in stooling blocks that will provide thousands of cuttings for rooting in production beds. Superior Populus clones have been propagated this way for years. Generally, clones are propagated and distributed separately, but there is increasing interest in distributing clonal mixes of several compatible clones. The idea is that several clones will provide some buffering capacity against pest outbreaks and help prevent complete plantation mortality.

Finally, officially named and released cultivars should be used when they are available and appropriate for the intended use. Cultivars are the culmination of a tree breeder's efforts to improve a particular species. Cultivars are tested over a variety of sites for several years to insure that they perform above average for that species and are worthy of release. They may be propagated from seed or vegetative parts. The area of adaptation is usually specified and its recommendations should be followed. Once again, don't try to "stretch" the area of adaptation. Lists of cultivars that have been released for use in conservation plantings have been published (Cunningham 1988).

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The Status and Future of USDA Forestry Research in the Great Plains[1]

W. J. Retveld, Stephen E. McDonald, Charles W. Fudge, and Gary L. Hergenrader[2]

Abstract.-- The number of USDA field units active engaged in tree-related research in the Great Plains has declined from nine to two in recent years, and funding is flat. Despite this decline in overall effort, the USDA Forest Service Unit in Lincoln, Nebraska is developing a novel research program of research on improvement of tree stress and pest resistance. In addition, a research and development initiative is being developed that will emphasize agroforestry systems that integrate tree windbreaks with conservation farming practices.

INTRODUCTION AND HISTORY

Before discussing the future involvement of the U.S. Department of Agriculture in Great Plains forestry research, it would be appropriate to briefly review its past involvement. Historically, the Forest Service and the Agricultural Research Service have played important and productive roles in researching and solving problems related to Great Plains forestry. The Soil Conservation Service has contributed significantly through the formulation of tree establishment and management guidelines, and the establishment of regional Plant Materials Centers. Great Plains land grant universities have made important contributions in conducting forestry research, establishing demonstration studies, and disseminating research results through their extension divisions. Several bibliographies and state-of-the art reviews have been compiled on Great Plains forestry and windbreak technologies (Alcorn and Dodd 1984; Brandle, Hintz, and Sturrock 1988; Campbell and Pratt 1974; Cunningham 1982; Loucks 1983; Read 1961).

USDA research installations devoted primarily to Plains forestry and related subjects in the Great Plains have been located at Bottineau, Mandan, and Denbigh, ND; Sidney, MT; Cheyenne, WY; Akron, CO; Lincoln, NE; Manhattan, KS; and Woodward, OK.

THE PRESENT

In contrast to the past, the number of Agricultural Research stations and Forest Service field units currently engaged in tree related research in the Great Plains has declined to two (Mandan, ND and Lincoln, NE, respectively) in recent years. Agricultural Research Stations adjacent to the Great Plains, which may have researched tree problems in the past, now emphasize research on grasses, agronomic crops, fruit trees, soil erosion, and other subject areas indirectly related to Plains forestry. Examples are the Northern Plains Soil and Water Conservation Laboratory at Sidney, MT, and the Wind Erosion Laboratory at Manhattan, KS. The Forest Service Shelterbelt Laboratory at Bottineau, ND, and the Wildlife Project at Lubbock, TX, were closed in 1982.

The research project: "Genetic Improvement of Trees for Soil and Water Conservation" at Mandan, ND, is the sole ARS project directly engaged in tree research in the Great Plains. This project has 1.3 scientist years assigned to tree-related research. Forest Service research relating directly to Great Plains forestry is centered solely at Lincoln, NE, and is staffed by five scientists. Thus there are presently only 6.3 USDA scientist years being devoted directly to forestry research in the Great Plains--a region containing one-fourth of the land area of the contiguous United States.

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[1]Paper presented at the Intermountain Nurserymen's Conference (August 15, 1989; Bismarck, ND).

[2]W.J. Rietveld is Project Leader, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Lincoln, NE; Stephen E. McDonald is Assistant Director, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO; Charles W. Fudge is Director of Timber, Forest Pest, and Cooperative Forestry Management, USDA Forest Service, Region 2, Lakewood, CO; and Gary L. Hergenrader is Nebraska State Forester, Professor, and Head of Department of Forestry, Fisheries, and Wildlife, University of Nebraska, Lincoln.

THE FUTURE

Despite the decline in USDA Plains forestry research, the possibilities for future scientific contributions to Plains forestry seem bright. A solid foundation of research knowledge has been laid. Procedures have been developed for procuring sound seed; raising quality nursery stock; growing containerized tree seedlings; designing, establishing and managing windbreaks and other plantings; controlling disease pathogens and insect pests; developing genetically improved strains of tree seed; and determining physiological, ecological and soils relationships to tree performance.

Now, Plains forestry research is entering a new and exciting era, with new tools available for research at the molecular, process, and whole plant levels. The probability for productive research is high indeed, with the availability of new computer technology and sophisticated research instrumentation, and a cadre of young, well-trained scientists in a variety of forestry-related disciplines.
Cunningham (1984) cited packaging of clonal mixtures of hardwood species; research in tree survival, cold hardiness, and drought hardiness; adaptability to problem soils; and selection and breeding for faster growth and more desirable form characteristics as future tree improvement research possibilities. Cunningham further pointed to biotechnology playing a significant role in the future of Plains forestry.

Concurrent with the new era of research at the process and molecular levels, there will be a need to continue and complete previously begun long-term studies of a more applied nature. Cunningham (1984), for example, cited the need to continue traditional tree improvement research consisting of provenance testing of newly introduced species, followed by selection, clonal and full-sib progeny testing, and seed orchard establishment.
Continuing research in soils, genetics, entomology, pathology, and windbreak establishment, management, and renovation should not be abandoned, but rather, should supplement and complement more basic research in these allied fields.

The prognosis for increases in USDA funding for Plains forestry research appears bleak for the foreseeable future. In FY 1988, the Rocky Mountain Station had the smallest percentage budget increase of all Forest Service Experiment Stations in the U.S.; and the Station's budget has been the smallest of all Station budgets for some years. The Station was larger in terms of people and funding 10 years ago than at present. Conversely, the Station has produced more research publications per scientist during the past three years than any other Forest Service Research Station in the United States. In fact, the Rocky Mountain Station produced more research publications last year than during any other year in its 50-plus year history. We conclude that the Rocky Mountain Station, of which the Lincoln field unit is a part, is productive, but not as competitive as we need to be.

SOME FOOD FOR THOUGHT

With 75 years[3] of Great Plains forestry research experience behind us, it is appropriate that we take time to reassess our situation. Following are several key points affecting and characterizing the direction of Great Plains forestry research:

1. The Great Plains is predominantly a semiarid food-producing region. There are few forests in the Great Plains. Most trees planted in the Great Plains are in cities, or in farmstead and field windbreaks where they must serve a specific purpose.

2. The Great Plains is characterized by environmental extremes and periodic droughts, and is threatened by predicted global climate changes. The trees we plant must have adequate stress and pest resistance to withstand present and future environments.

3. Great Plains agriculture is experiencing some stress of its own from: a) low farm income and high subsidies, b) growing public concern with agri-chemical pollution and food contamination, c) periodic droughts and water shortages, d) topsoil loss, e) surface and groundwater contamination, and f) lack of sustainability of present high-input farming systems. A crisis situation is building, but it's not readily apparent to everyone, as was the dust bowl.

4. The Great Plains holds 71.5 percent of U.S. cropland where wind erosion is greater than the soil loss tolerance of 5 tons/acre/year (USDA 1987), yet only 3.5 percent of this land is protected by windbreaks. The present 1 million acres of windbreaks produce \$700 million/year[4] in benefits (Rietveld 1989, unpublished data). Two-thirds of these windbreaks are aging and in need of renovation (Fewin and Helwig 1988). Unless cost-effective renovation techniques are developed and promoted, we expect the present net loss of windbreaks (0.4 percent /year) to escalate.

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[3]Agricultural Research Service shelterbelt research in Mandan, ND began in 1914; Forest Service windbreak research in Lincoln, NE began in 1953.

[4]Rietveld, 1989; estimated from available data. A subsequent publication will present details of estimating the value of windbreak benefits and an economic analysis of agroforestry in the Great Plains.

5. The Conservation Reserve Program (CRP) is a lost opportunity for Great Plains forestry (Deneke and Bratton, in press). As of the seventh signup, only 20,500 acres (0.13 percent) of the 16 million acres enrolled in CRP in the 10 Great Plains states were planted to trees; 90 percent of the remaining acres were planted to grasses. Unfortunately, when the program expires in 10 years, most of these highly erodible lands can, and probably will, be plowed again.

6. Great Plains forestry lacks a clearly defined role in the national scene because of the lack of timber production and lack of understanding of the value of agroforestry. Consequently, federal funding for Great Plains tree-related research is declining.

7. The Great Plains region is representative of millions of acres of semiarid lands westwide and worldwide where tree planting for crop, animal, and road protection; soil and water conservation; water quality; biological diversity; recreation and wildlife benefits; environmental quality; and socio-economic benefits are more important and more valuable than timber production.

Considering these key factors, two main implications stand out: (1) there are enormous potential benefits from tree planting in the Great Plains, and (2) Great Plains forestry is languishing because of its low priority. Although we, as foresters, recognize that trees should be an integral part of the Great Plains ecosystem, we must also recognize that trees, like any other crop, must be economically justifiable in a predominantly agricultural community. Promoting tree planting from the standpoint that "trees are nice" will have moderate success, mostly in establishing urban and farmstead trees, but the real need is in establishing field windbreaks. In the fields, trees most definitely must: (1) have a definite purpose, (2) be suited to the task, and (3) be economically justifiable, or they simply won't be planted or won't be kept.

Our research, technology transfer, and education efforts in the Great Plains must go beyond "trees are nice" and "plant trees for protection". We must broaden our scope and develop and deliver complete, integrated, and fully tested agroforestry systems. Agroforestry, as applied to the semiarid Great Plains, is defined as: a sustainable land management system that synergistically integrates the wind erosion and crop protection of tree windbreaks with the water erosion protection of conservation farming practices, thereby fully protecting the soil resource, stabilizing and optimizing productivity, and providing additional amenities. Thus, in the Great Plains, the primary agroforestry benefits are from soil and crop protection; other benefits are secondary in comparative value, yet highly significant.

To accomplish such an undertaking, we need to develop partnerships with agricultural scientists. From a forestry research standpoint, an immediate need is to focus on developing trees especially suited for field windbreaks, and to develop appropriate agroforestry windbreak technologies. This is discussed further in the following sections.

In our present role as Great Plains foresters, we obviously have a lot to offer, but as evidenced by CRP, a lot of people are not listening. Why? We need to take a hard look at our identity, priority, acceptance, and future role in the Great Plains agricultural community. If we are to realize the fruits of our new research potential, we must become more politically astute and proactive in promoting the importance and value of Great Plains agroforestry and collectively competing for the available research dollars. And we must do it as intensively as we have cooperated in the past to solve important and difficult research problems.

PROGRAM REDIRECTION

Over its 36-year history, the Lincoln, NE field unit of the Rocky Mountain Station has produced a valuable foundation of research information on tree improvement, windbreak establishment and management, and pest biology and management. Technology transfer in the Great Plains will be enhanced with USFS State and Private Forestry establishing two new Forest Pest Management positions at Rapid City, SD and transferring its Great Plains Forestry Specialist to Lincoln. These factors, along with personnel changes at Lincoln, make program re-direction possible.

The new research emphasis at Lincoln will be to "Improve stress and pest resistance of Great Plains tree species." We feel that more emphasis needs to be placed on research that focuses on our basic understanding of the interactions of tree physiology and genetics, environmental stresses, and pest populations in order to achieve more ecologically sound, biologically acceptable, long-term solutions to Great Plains forestry problems. Our general hypothesis is: lack of adaptation and environmental stresses lower tree vigor, which predisposes them to pest attack. These pests cause further stresses, which result in tree decline and premature death. Our new interdisciplinary research will emphasize molecular genetics, stress physiology, pathology, and entomology. Specific objectives are to: (1) screen for intraspecific differences in tree stress and pest resistance, (2) understand tree vigor/pest/natural enemies/environment interactions, (3) develop tree adaptability models for the Great Plains, (4) understand mechanisms of tree stress and pest resistance, and (5) develop stress and pest resistant trees.

This research effort, under existing funding levels, is now possible because of the wealth of provenance tests established in the Great Plains that will provide a diversity of genetic materials, and the solid foundation of basic biological information on Great Plains species. Despite the emphasis on new science and technology, our focus will be highly applied. Our approach will be process-oriented so we understand the key interrelationships, but we will strictly adhere to the goal of producing more stress- and pest-resistant trees. We anticipate that this strategy will not only focus on the root causes of Great Plains forestry problems, but will also vastly improve our competitiveness for research dollars.

A GREAT PLAINS AGROFORESTRY INITIATIVE

We believe the real key to the success of Great Plains forestry is developing, packaging, delivering, and suppporting complete, integrated, and sustainable agroforestry systems. Such an effort cannot be accomplished under current research funding levels. Thus, we have developed an initiative to establish a center for semiarid agroforestry research, development, and technical assistance at Lincoln, NE. The 20-year research, development, and demonstration program would develop economically and environmentally sound sustainable agroforestry systems, attain public acceptance of windbreak technologies and conservation farming practices, and improve the quality of life in semiarid environments. Our goal is to convert at least 12 million of the 48.2 million acres of highly wind-erodible lands in the Great Plains to agroforestry during the 20-year program.

The components of the agroforestry program include: (1) Forest Service research on improving tree resistance to stress and pests, as previously described; (2) Forest Service, Soil Conservation Service, and Agricultural Research Service interagency cooperative research and development on windbreak technologies, tree improvement, biological control of tree insect pests, economic evaluation, and social science; (3) supporting extramural research on related subjects by Great Plains universities; (4) agroforestry demonstration areas in Great Plains States in cooperation with state forestry agencies and agricultural experiment stations; (5) technical assistance on tree pest management by USDA Forest Service State and Private Forestry personnel co-located at the Center, working in cooperation with State forestry agencies, Agricultural Extension Agents, and Soil Conservation Service; (6) agroforestry technical assistance by the Soil Conservation Service, State forestry agencies, and Agricultural Extension Service; and (7) international exchange of agroforestry information by USDA international liaison personnel co-located at the Center.

Specific goals to be accomplished by the agroforestry center and its cooperators are: 1) develop sustainable agroforestry systems that will minimize topsoil loss and water contamination while maintaining crop productivity and farm income; 2) adapt, demonstrate, document, and model the effectiveness of agroforestry under different farming systems and soil/climate conditions; 3) develop genetically superior trees for windbreaks that will have improved stress and pest resistance and a longer effective lifespan; 4) increase farmer and public acceptance of sustainable agroforestry systems; and 5) increase biodiversity, wildlife habitat, recreation opportunities, and environmental quality.

An ecomonic analysis of various program alternatives revealed that the 20-year program, in combination with existing cost-sharing programs, could convert 12 million acres of highly wind-erodible land to agroforestry with an average benefit:cost ratio of 170 and net present value (4 percent) of $10.88 billion. In combination with new cost-share and land rent incentives (e.g., 75 percent tree planting cost-share plus rent on land occupied by windbreaks during the tree establishment period), 24 million acres could be converted to agroforestry, with an average benefit:cost of 86 and net present value (4 percent) of $21.68 billion.

We have developed a prospectus for the Great Plains Agroforestry Center, and are in the process of contacting cooperators to enlist their support. We have been working closely with Senators James J. Exon (D-NE) and Robert Kerry (D-NE), and are developing strategies to include the Great Plains agroforestry program in legislation before the Congressional session beginning in Sept. 1989. If our efforts are successful, the establishment of the Great Plains Agroforestry Center and umbrella of cooperative programs would be a strong boost for everyone concerned with Great Plains forestry, and would clearly define the future direction of forestry in the Great Plains.

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Soil Fumigation in Bareroot Tree Nurseries[1]

Thomas D. Landis and Sally J. Campbell[2]

Abstract.--This paper gives a general overview of fumigation in bareroot tree nurseries in the United States. Application methods, biological activity, behavior in the environment, risks, to human health, and economics are discussed. Information is presented for the more commonly used fumigants: methyl bromide, chloropicrin, dazomet, metam-sodium, and vorlex.

INTRODUCTION

Chemical fumigants have been used in forest nurseries since the early 1900's when formalin, an aqueous solution of formaldehyde gas, was recommended for control of fungal damping-off (Tillotson 1917). Other chemical fumigants were tested in forest tree nurseries in the late 1940's. Methyl bromide was initially used for weed control, but was also found to control damping-off fungi (Niner 1951), white grubs, and nematodes (Clifford 1951). Ethylene dibromide was found to be both effective and economical in controlling root rot at a southern nursery, costing less than $50 per acre ($123 per hectare) (Henry 1951). Methyl bromide fumigation was considerably more expensive at over $600 per acre ($1482 per hectare) (Clifford 1951).

In the years since those early trials, chemical fumigation of seedbeds has become an accepted pest control practice in forest tree nurseries. A survey of nursery soil fumigation practices in 1981 reported that over 90 percent of southern and western nurseries used fumigants to control a broad spectrum of nursery pests but was primarily used for weed and disease control. Around 90 percent of all soil fumigation was done with methyl bromide and methyl bromide/chloropicrin, with Telone, Vorlex, and Vapam used occasionally (Ruehle 1986). A more recent survey of Federal nurseries in Washington and Oregon revealed that fumigants still account for 93 percent of annual pesticide use, with methyl bromide/chloropicrin and dazomet the most popular chemicals (table 1).

Soil fumigation is an interesting topic for several different reasons. It is one of the most expensive cultural operations in a nursery, presently costing around $1,000 per acre ($2470 pe hectare) or more. Because of this high cost, chemical fumigation can only be economically justified on the most valuable agricultural crops such as seed tobacco, strawberries, and ornamentals. Soil fumigation is also effective - it works. As previously mentioned, fumigation is the most effective pest control practice used in forest nurseries today, and nursery managers consider pre-sowing fumigation to be a normal part of the cultural sequence. But soil fumigation has become controversial in recent years because of concern about the safety of these biocides, both a the nursery and in the surrounding area. Other concerns include disposal of fumigation tarps, possible groundwater pollution, and adverse effect on beneficial soil microorganisms. These issues have forced nursery managers to take another look at the soil fumigants that they are currently usin and reevaluate other pest management options.

PHYSICAL AND CHEMICAL PROPERTIES OF COMMON NURSERY FUMIGANTS

Four chemicals have commonly been used for soil fumigation in forest nurseries in the United States and Canada in recent years (table 2).

Methyl bromide/chloropicrin (MBC) is availabl in two common formulations: one containing 2 percent chloropicrin (MBC-2), and another containing 33 percent chloropicrin (MBC-33). The chloropicrin in MBC-33 is an active fumigant, whereas that in MBC-2 is only added as a tracer to the methyl bromide, which has no detectable odor. MBC is available from several different manufacturers under a number of different trade names (table 2). MBC is applied as a pressurized liquid that changes into a gas when injected into the soil. This pervasive fumigant is always covered with a one or two mil [0.001 to 0.002 in. (0.025 to 0.051 mm)] thick plastic tarp, which is impermeable to the fumigant gases.

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Table 1 - Average annual pesticide use in Federal forest nurseries in Oregon and Washington

Pesticide	Pounds of Active Ingredient	Percent[1] of Total
Fumigants		
MB-C	33,250	66
Dazomet	13,461	27
SUBTOTAL	46,711	93
Herbicides		
Bifenox	1,425	3
DCPA	420	1
Dicamba	25	<1
Diphenamid	585	1
Glyphosate	44	<1
Oxyfluorfen	320	1
SUBTOTAL	2,819	6
Fungicides		
Benomyl	102	<1
Captan	60	<1
Chlorothalonil	414	1
DCNA	60	<1
Metalaxyl	58	<1
SUBTOTAL	694	<1
Insecticides		
Acephate	3	<1
Carbaryl	3	<1
Chloropyrifos	50	<1
Fenvalerate	15	<1
Malathion	6	<1
SUBTOTAL	77	<1
TOTAL	50,491	100

[1] = < means less than listed value

Source: USDA Forest Service (1989)

Two tarping techniques have been used for covering injected fumigants. Continuous tarping is a operation in which each strip of plastic tarp is glued to the previous one, resulting in the entire field being covered with a solid sheet (fig. 1). Another alternative technique is strip fumigation where the fumigant is applied under separate sections of tarp that are covered on both sides with soil (fig. 2). After the prescribed treatment period has passed, the untreated strips of soil must be fumigated to provide complete coverage. Under either system, the tarp must remain intact during the entire fumigant exposure period. If the integrity of the fumigation tarp is broken before the end of the treatment period (fig. 3), then these areas must then be retreated.

Dazomet, also known as Basimid Granular[R], is a unique formulation for a fumigant because it is applied as a very fine granule that converts into a gas when it encounters water in the soil. These

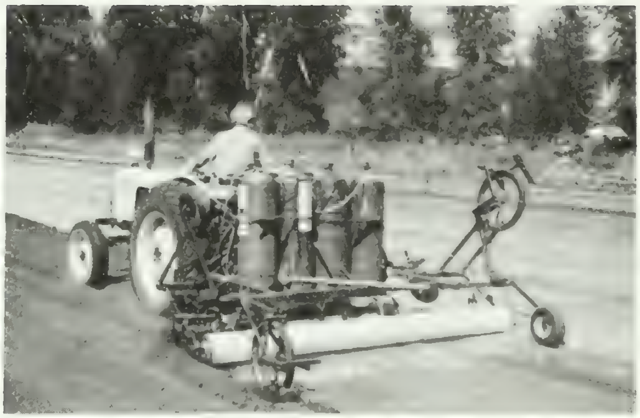

Figure 1 - Continuous tarp fumigation consists of glued, overlapping sheets of fumigation tarp which form a solid cover.

Figure 2 - Strip fumigation consists of treating separate strips of the field, and then returning to fumigate the untreated sections.

Figure 3 - Wind can break the glue seal between adjacent strips of fumigation tarp before the exposure period is completed, requiring the area to be retreated.

Table 2 - Physical and chemical properties of common soil fumigants and their application in forest nurseries

Chemical Name	Trade Name(s)	Active Ingredients/ (Breakdown products)	Formulation/Activity	Application Methods
Methyl bromide + chloropicrin	Brom-O-Gas[R] MBC-33[R] Meta-Brom 98[R] Namco Pathofume B[R] Pic-Brom 33[R] Terr-O-Gas 67[R]	Two formulations: 98% methyl bromide + 2% chloropicrin and 67% methyl bromide + 33% chloropicrin	Liquified gas, bottled under pressure. Volatilizes at ambient pressure and temperature	Injected into the soil, and covered with plastic tarp
Dazomet	Basamid-Granular[R]	Tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione (Methyl isothiocyanate)* (Formaldehyde) (Hydrogen sulfide) (Monomethylamine)	Fine crystalline solid Volatilizes after contacting soil moisture	Incorporated into the soil, and sealed with roller and/or water
Metam-sodium	Vapam[R] Metam[R] Soil-Prep[R] Nemasol[R]	Sodium N-methyldithiocarbamate (Methyl isothiocyanate)	Liquid. Volatilizes after application to soil.	Injected into irrigation system, or into soil
Vorlex	Vorlex[R]	80% Dichloropropene/ dichloropropane 20% Methyl isothiocyanate	Liquid. Volatilizes after application to soil	Injected into soil; may or may not be tarped

* = () indicates the breakdown product and active fumigant gas

Source: modified from Thomson (1988)

"micro-granules" are normally applied through drop-type spreaders (fig. 4), immediately incorporated into the soil (fig. 5), and physically contained with a roller or water-sealed with sprinkler irrigation. The fumigant activity results from the interaction of a mixture of different gases, the most common being methyl isothiocyanate - MITC (table 2).

Metam-sodium (Vapam[R]) is a liquid fumigant that also converts to MITC gas in the soil (table 2). It can be either injected into the irrigation system and applied through sprinklers, or directly injected into the soil. Although this fumigant can be water-sealed like dazomet, the label recommends that it can be covered with plastic tarp "for better results."

Vorlex is a liquid fumigant that volatilizes into a mixture of different fumigant gases: dichloropropane/dichloropropene, and MITC (table 2). This fumigant is soil-injected, and may or may not be covered with a plastic tarp (fig. 2).

Figure 4 - The fumigant dazomet is a fine "microgranule", which is applied with drop-type fertilizer spreaders.

Figure 5 - After application, the dazomet granules are incoporated into the soil and sealed with a roller or water seal.

BIOLOGICAL ACTIVITY OF MAJOR FUMIGANTS

Although fumigants are commonly thought to be biocides that kill all organisms, there are differences in effectiveness between the different chemicals. The common nursery fumigants are not equally effective against the four major groups of nursery pests: fungi, insects, nematodes, and weeds (table 3). The concept of a "target pest" is important when choosing a control method. Fumigation should never be used as an all-purpose pest control treatment; instead, target pests should be identified and all control options analyzed before a fumigant is used.

Fungi

All fumigants do a reasonably good job on the common soil pathogenic fungi, especially at the higher application rates (James 1989). The MBC-33 formulation is the only one that can control the more resistant fungal pathogens such as Cylindrocladium spp. and Macrophomina phaseolina [(Maub.)Ashby] that form resistant resting stages called sclerotia. Luckily, these persistent pathogens are not found in nurseries in cooler environments. Cordell and Wortendyke (1972) provide a good review of the older literature on the relative effectiveness of the methyl bromide formulations compared to other fumigants.

Based on many early trials, MBC-33 became the standard fumigant for forest nurseries in the United States. Dazomet, however, is becoming increasing popular as an alternative to methyl bromide fumigation in recent years. McElroy (1986) tested MBC-33, dazomet, metam-sodium, and vorlex at several Pacific Northwest nurseries and found that all gave good control of Fusarium spp. and Pythium spp., the principal soil pathogens in that area. Tanaka and others (1986) also did fumigation trials at two nurseries in this region, comparing dazomet to MBC-33 at two application rates [the standard 360 lb/ac (404 kg/ha), and a 2X rate]. They also monitored soil populations of Pythium and Fusarium and found that dazomet was nearly as effective as the standard rate of MBC-33, and that the 2X rate of MBC-33 was not justified. Campbell and Kelpsas (1988) report that fall fumigation with MBC-33 was more effective than dazomet or metam sodium in

Table 3 - Relative pest control effectiveness of common nursery fumigants

	Fungi	Insects	Nematodes	Weeds
MBC-33*	Yes	Yes	Yes	*Most*
MBC-2	*Most*	Yes	Yes	*Most*
Dazomet	*Most*	Yes	Yes	*Most*
Metam-Sodium	*Most*	Yes	Yes	*Most*
Vorlex	*Most*	Yes	Yes	*Most*

*Methyl bromide/chloropicrin comes in two major formulations: 67%:33% and 98%:2%

reducing soil populations of Pythium and Fusarium through the spring sowing period. James (1989) reported that, while dazomet and MBC-33 both lower populations of pathogenic fungi, MBC-33 provides a longer period of control.

The relationship of soil pathogen population levels to seedling disease and growth is unclear, however. Tanaka and others (1986) found that MBC-33 gave better control of Fusarium root rot infections and produced significantly larger Douglas-fir [Pseudotsuga menziesii (Mirb.)Franco] seedlings than dazomet. On the contrary, Campbell and Kelpsas (1988) found that dazomet produced significantly larger ponderosa pine (Pinus ponderosa Laws.) seedlings than MBC-33; metam-sodium seedlings were also larger, although the differences were not statistically significant.

Insects and Nematodes

All of the fumigants do a reasonably good job of controlling soil insects and nematodes (table 3). Insect damage is rarely severe enough to justify fumigation on its own, but nematodes have been the main target pests for fumigation in forest nurseries. MBC fumigants provide excellent control of nematodes in forest nurseries (Ruehle 1975), and the MBC-2 formulation is generally recommended. Both MBC-33 and dazomet at the 350 lb/ac (393 kg/ha) rate controlled populations of the root lesion nematode (Pratylenchus penetrans Cobb), although a lesser rate of dazomet (150 lb/ac = 168 kg/ha) had less effect (McElroy 1986). Peterson and Riffle (1986) caution that, while fumigation greatly reduces the nematode populations in soil, it does not completely eradicate them.

Weeds

Weeds are sometimes the primary target pest for fumigation (Grierson 1989), but none of the fumigants control all species of weeds (table 3). MBC-33 is not as effective for controllings weeds as MBC-2 at standard application rates, but is a good herbicide at a 400 lb/ac (449 kg/ha) rate (Ruehle 1986). Methyl bromide also tends to scarify the seed coat of hard-seeded weed species such as many legumes, and actually stimulate germination immediately after fumigation. This may be beneficial in the case of fall fumigation because the recently germinated weeds are soon killed by frost. Vorlex was found to give less weed control than the other fumigants in a Pacific Northwest nursery (McElroy 1986). Since little data has been reported on which weed species are resistant to which fumigants, it would be wise to contact chemical company representatives and other nursery managers before selecting a fumigation chemical.

Microbial Reinvasion of Fumigated Soil

Because "nature abhors a vacuum", fumigated soil will eventually become recolonized by a full complement of endemic microorganisms, both beneficial and pathogenic. Even the most effective soil fumigation can be ruined if the target pest is able to rapidly reinvade the treated soil.

The most common source of reinvading microorganisms is from adjacent untreated soil, but they can also move up from soil strata underneath the fumigated layer. Reinvasion studies with the pathogenic fungus Fusarium oxysporum f. sp. melonis (Snyd. and Hans.) have shown that, although the fungus could not be isolated from fumigated soil after 6 days, by 32 days, the pathogen was isolated consistently from the outer edges of the treated area. There was also evidence that the fungus was reinvading from lower untreated soil layers because, after 10 weeks, there was a distinct population density gradient from below the fumigated layer to the soil surface (Marois and others 1983). Vaartaja (1967) studied the development of several soil microorganisms after fumigation and found that reinvasion by fungi occurred in several ways: rain splash, irrigation water, blowing dust, and soil carried on boots. Another probable source of contamination is nursery tillage equipment that carries soil from untreated to treated fields.

Rapid reinvasion with benefical microorganisms is desirable. Many fungal species that form mycorrhizae produce air-borne spores that can blow into fumigated soils within a few months after fumigation. The fungi that form endomycorrhizae, however, are slower recolonizers because their spores are not carried by air and must be reintroduced on soil particles (Marx and others 1989). Actually, beneficial microorganisms may be the first to reestablish in fumigated soil. Fungi of the genus Trichoderma spp. and bacteria are among the earliest colonizers (Vaartaja 1967), and Trichoderma may be responsible for the positive seedling growth response often observed in fumigated soils (Ingestad and Nilsson 1964).

To slow the rate of reinvasion by soil-borne pathogens, nursery managers should reduce obvious sources of recontamination such as transported soil and surface water runoff. Nursery implements should be cleaned before being used in fumigated soil; some nurseries use portable steam cleaners to both clean and sterilize their equipment. Fumigated fields should be physically isolated by a ditch or other type of drainage system to intercept surface runoff which can carry contaminated soil particles or motile spores of water mold fungi. Because reinvasion will eventually occur, nurseries should schedule fumigation as close to the date of sowing as is practically possible. Obviously, fall-fumigated fields are more liable to recontamination than spring-fumigated ones; in many bareroot nurseries, however, fall fumigation is the only option because spring soil temperatures are too low to allow early fumigation. Reinvasion is usually slower in soils which have had pathogen populations reduced to near zero (e.g. after MBC fumigation), as compared to soils where a low residual population of pathogens remain after treatment (e.g. after dazomet fumigation).

APPLICATION CONSIDERATIONS FOR SOIL FUMIGATION

Relative Safety of Application

The primary consideration when selecting a fumigant should be worker safety. All the common fumigants are hazardous chemicals, but the MBC formulations and vorlex are "restricted use pesticides," which means that they can only be applied by specially trained, certified applicators. Because of their concerns about nursery worker safety, many nursery managers choose to contract their MBC soil fumigation. Dazomet and metam-sodium are relatively less hazardous to apply, and so most nurseries do their own fumigation with these chemicals.

Soil Properties

Soil temperature is critical to the effectiveness of all fumigants because the vapor pressure of any gas is a function of temperature. The temperature will, therefore, determine how quickly the fumigant gases pervade the soil particles and also define their persistence in the soil. In the case of the granular dazomet, temperature controls the speed of conversion of the solid particles to a gas (Neumann and others 1984). Warm soil temperatures, in the presence of moisture, also increase the metabolism of nursery pests and make them more susceptible to the fumigants (Boone 1988).

Although some soil fumigants are reported to be effective at colder temperatures, the lower temperature limit for all fumigants should be 50°F (10°C) at a soil depth of 6 inches (15 cm). Because soil temperatures take too long to warm in the spring, most northern nurseries fall fumigate while soils are still warm. Dazomet should not be applied if soil temperatures are too warm, however; Thomson (1988) recommends an upper limit of 90°F (32°C). Soil temperatures can also affect the fumigation technique; tarping is recommended for vorlex if the temperature exceeds 75°F (24°C)(Thomson 1988).

Fumigation effectiveness is also a function of soil moisture content, which should usually be in the range of 50 to 75 percent of field capacity (Boone 1988). Moist soil promotes good tilth which leads to good fumigant penetration. Again, soil moisture stimulates nursery pests to their most susceptible state (germinating weed seeds, fungi in the mycelial state, and emerging nematodes). For the granular dazomet, a soil moisture content of 60 to 70 percent is necessary for rapid conversion to a gas (Neumann and others 1984). The soil seal that is recommended for dazomet, and possibly other similar fumigants, should be maintained by periodic light irrigations for 3 to 5 days after application (Thomsom 1988). Soil can also be too wet for effective fumigation, however. Overly wet soil can form large clods when tilled and also has a high percentage of pores filled with water, both of which restrict fumigant penetration.

The physical condition of a soil is also important for effective fumigation. Soil should be tilled to a a moderate-sized crumb structure if possible to generate a large proportion of macropores to carry the fumigant gases. The high surface-to-volume ratio of large clods inhibits fumigant penetration, whereas the numerous small particles that are produced in a overworked soil create micropores that slow movement of fumigant gases.

Soil organic matter content should also be considered. Undecomposed organic matter may inactivate the fumigants (Boone 1988). In the case of dazomet, the effective gases may be bound by the organic matter itself or by the ammonia created as the organic matter breaks down (BASF 1984). Green manure or cover crops should be turned under and organic amendments applied long enough before fumigation to allow complete breakdown. Organic matter may also delay dissipation of the fumigant gases; it is recommended that crops not be sown until at least 30 days after fumigating high organic soils with metam-sodium (Thomson 1988).

Exposure and Aeration Periods

The mandatory waiting period between fumigation and sowing the seedling crop consists of two different intervals: the exposure period, in which the fumigant gas is active, and the aeration period, when the gas is allowed to dissipate from the treated area. The aeration period is normally followed by a germination test (table 4). This consists of sowing seeds from a rapidly germinating species, such as radish or lettuce, in a small sample of soil from the fumigated area. A non-fumigated control soil sample should also be taken at the same time for comparison. Both soil samples should be placed in lidded glass jars and watered. At the end of about 5 days, the seedlings should have emerged and be developing normally (fig. 6); poor germination or distorted growth means that some fumigant fumes still persist in the soil.

The recommended number of days for the two fumigation waiting periods depends on soil temperature and weather conditions, but the total period can range from 8 to 50 days for MBC or dazomet (table 4). Dazomet typically requires a longer period under normal nursery fumigation conditions, however; because MBC is immediately converted into a gas, it becomes active more rapidly than the granular dazomet. At a typical soil temperature of 50°F (10°C), the exposure period for dazomet will take 12 days, compared to 3 days for MBC. Wet weather can cause problems with fumigant dissipation, particularly with the granular dazomet. McElroy (1986) reported that 1 inch (2.5 cm) of rain after dazomet fumigation moved the fumigant deeper into the soil; this delayed the escape of the fumigant, resulting in phytotoxicity to the crop seedlings. Similar consequences have been observed with the chloropicrin component of MBC (McElroy, personal communication).

Table 4 - The effect of soil temperature on fumigation waiting periods

	Methyl Bromide/ Chloropicrin	Dazomet
Fumigant Applied and Soil Sealed		
Exposure Period (Gas Activity)	1 to 3 days	4 to 25 days
Tarp Removed or Soil Seal Broken		
Aeration Period (Gas Escapes)	2 to 14 days	2 to 20 days
Test For Residual Fumes		
Germination Testing	5 days	5 days
Sow Crop		
Total Waiting Period	8 to 22 days	11 to 50 days

Source: BASF (1984)

Figure 6 - At the end of the aeration period, a germination test should be performed on the fumigated soil to make certain that it is safe to plant the crop.

ECONOMICS OF SOIL FUMIGATION IN FOREST TREE NURSERIES

Because fumigation is such an expensive cultural practice, it is necessary for nursery managers to provide economic justification. In a successful nursery operation, economic realities mandate that the costs of fumigation be offset by the benefits of the practice.

Fumigation Costs

The cost of fumigation can be prohibitive in smaller nursery operations, where cash flow problems make it difficult to come up with the money for fumigation so early in the crop cycle. Fumigation is also less expensive for larger nurseries because many fumigation contractors have the same set-up charge regardless of the amount of acres to be treated. Nurseries in remote locations are also at an economic disadvantage because contractors must reflect travel costs in their fees. One way to save money on fumigation contracts is to coordinate the timing of fumigation with other nurseries in the general area so that the contractor can visit each operation on an efficient travel circuit.

Soil fumigation costs can vary between chemicals. Campbell and Kelpsas (1988) reported that the per-unit chemical cost of applying MBC-33 was similar to dazomet, while the metam-sodium chemical costs were less. The 1989 soil fumigation costs for the 10 USDA Forest Service nurseries averaged around $1,200/ac ($2,964/ha) for MBC contracts, and around $1,000/ac ($2,470/ha) for nursery-applied dazomet (table 5). These figures reflect chemical and application costs, as well as the cost of tarp removal in the case of MBC.

Table 5 - Statistics on soil fumigation costs for USDA-Forest Service nurseries in 1989.

	Fumigation Costs Per Acre	
	Contract Application	Nursery Application
Methyl bromide/chloropicrin		
Number of nurseries	5	1
Average	$ 1,137	$ 902
Range	$942 to $1280	N/A[1]
Dazomet		
Number of nurseries	0	4
Average	N/A	$1,032
Range	N/A	$938 to $1173

[1] N/A = Not applicable

Benefits from Fumigation

The benefit side of the economic scale can be subjective, and figures are often outdated because the comparisons were only done when fumigation was first implemented. One easy way to determine fumigation benefits is to leave one or more small "check" or untreated areas in the seedbed so that seedling yield information can be compared to fumigated areas. Growth information, such as seedling height, caliper, biomass, and root growth, should be collected at intervals during the growing season because the benefits are sometimes only visible at one time during the rotation. The true test of fumigation benefits, however, is to harvest seedlings from each area and have them graded; this will generate actual "shippable seedling" data that can be converted back into dollars and compared to fumigation costs.

BEHAVIOR OF FUMIGANTS IN THE ENVIRONMENT

Because fumigants are highly toxic pesticides, there is widespread concern that they or their breakdown products may contaminate the water, air, or soil in the nursery or in adjacent areas. The physical properties of fumigants determine how readily they move or persist in the environment after application; environmental factors, such as soil characteristics and amount of rainfall, also influence contamination potential and persistence. Several physical characteristics for MBC and dazomet determine their pollution potential in the environment (table 6).

Water Quality

Both surface and groundwater can become contaminated with pesticides from surface water runoff or leaching through the soil profile. The likelihood that a particular fumigant will contaminate water is dependent on a number of factors, including soil characteristics, pesticide characteristics, the local climate, amount of precipitation and/or irrigation, number of applications of the pesticide, rate at which the pesticide is applied, surface and groundwater hydrology of the site, drainage system at the site, and cultivation practices used at the site to increase infiltration (USDA Forest Service 1989).

The most significant factors affecting water pollution by pesticides are solubility in water and leaching potential (table 6). Pesticides must first dissolve in the soil water before they can leach downward. The situation concerning the solubility of fumigants in water is confusing because the solubility of a gas in water is usually measured under greater atmospheric pressure than that normally encountered in nursery soil (Chemical Fate Testing Guidelines 1983). Even though MBC is given a "moderate" solubility rating in water (table 6), it is estimated that only about 0.1 % of the applied MBC would ever leach from the nursery soil (USDA Forest Service 1989). Even though dazomet has a "high" water solubility rating, the leaching potential for its principal active ingredient (MITC) is negligible due to its rapid degradation in the soil and its high volatility (table 6). In fact, no groundwater contamination by methyl bromide, metam sodium, or MITC has yet been detected in the United States (Parsons and Witt 1988), although traces of MBC were identified in groundwater in Holland (Rattink 1984).

Table 6 - Effect of physical properties of methyl bromide/chloropicrin (MBC) and dazomet on water, soil, and air pollution

Pollution Site	MBC	Dazomet
Water		
Solubility in water[1]	Moderate	High
Leaching potential	Low	Negligible
Soil		
Persistence in soil[2]	Low	Low
Decomposition mode	Biological and chemical	Chemical
Air		
Volatility[3]	High	High

[1] Solubility is rated as High (> 100 ppm), Moderate (1-100 ppm), and Low (< 1 ppm).

[2] Persistence is rated in half-lives: High (> 180 days), Moderate (30-180 days), and Low (< 30 days).

[3] Volatility is rated in vapor pressure units: High (> 1.00 mm Hg), Moderate (0.001 - 1.00 mm Hg), and Low (< 0.001 mm Hg).

Source: USDA-Forest Service (1989)

Groundwater contamination by 1,2-dichloropropane and 1,3-dichloropropene, two components of the fumigant vorlex, has been detected in a number of states (Parsons and Witt 1988). However, it has not been determined that these occurrences were due to vorlex contamination because these two chemicals are found in other fumigants, such as D-D, and are also used for other non-agricultural purposes.

Surface water run-off can occur when rainfall or irrigation exceed the infiltration capacity and water flows over the soil surface or when water moves laterally through the soil profile into a surface water source such as a stream or drainage ditch. Surface water can become polluted either directly with soluble pesticides or when non-soluble pesticides are adsorbed onto soil particles and carried along with surface water flow. The surface water run-off potential for MBC is considered negligible (USDA Forest Service 1989); the situation for dazomet, vorlex, or metam-sodium is unclear but should not be significant.

Soil Quality

Two physical characteristics of fumigants that affect the soil pollution potential are persistence in soil and the type and rate of decomposition.

The soil persistence of MBC is rated low (table 6) because MBC is rapidly broken down by both biological and chemical means (USDA Forest Service 1989). MBC and inorganic bromide residues are absorbed by plants and animals; MBC is metabolized and the inorganic residues are relatively non-persistent. There is very little information about the environmental fate of chloropicrin, including its persistence in the soil (USDA Forest Service 1986).

Following incorporation, dazomet is also relatively non-persistent in soil (table 6). This fumigant chemically breaks down into many different products, all of which are lost from the soil within a few days through further degradation and volatilization, which are dependent on soil moisture and temperature. Soil type and pH also influence the effectiveness of the fumigant and its rate of breakdown. Soils with high clay or organic matter content can bind MITC, thus reducing its effective concentration (BASF 1984) and intermediate pH values (around 6.5) maximize degradation. (USDA Forest Service 1987). There is little information on metam-sodium, but, since MITC is the primary breakdown product, its behavior in soil should be similar to that of dazomet.

Persistence of 1,3-dichloropropene (1,3-D, a component of vorlex) in the soil is considerably

higher; the half-life of 1,3-D is 14 to 180 days, depending on environmental conditions. 1,3-D disappears through degradation (biological and non-biological hydrolysis), dispersion through the soil, volatilization into the air, and irreversible binding to soil particles. Temperature and soil moisture influence the rate of these processes (USDA Forest Service 1987).

Air Quality

Since fumigants are gases or volatilize after application, there is potential for drift into adjacent areas (table 6). The labels on all four fumigants direct the applicator to seal the soil surface in some fashion (water seal, rolling, or plastic seal) after application. If properly

Table 7 - Toxicity of common nursery fumigants in relation to other chemicals

Toxicity Category	Pesticide Label Signal Words	Pesticides and Other Chemicals	Acute Toxicity[1] Oral LD_{50}	Other
I-Severe	Danger-Poison		0-50 mg/kg	
		Chloropicrin	38	Dermal = 100 mg/kg Inhalation = 0.178 to 150 mg/l
		Nicotine	50	
II-Moderate	Warning		50-500 mg/kg	
		DDT	100	
		Caffeine	200	
		Methyl bromide	214	Inhalation = 4.5 mg/l
		Dazomet	363	Dermal = 200 to 10,400 mg/kg Inhalation = 302 to 60,000 mg/l
		Vorlex	538	Dermal = 470 to 961 mg/kg Inhalation = 11 mg/l[3]
III-Slight	Caution		500-5,000 mg/kg	
		Metam-sodium	820	
		Aspirin	1,700	
		Table Salt	3,750	
		Glyphosate	4,320	
IV-Very Slight	Caution		5,000-50,000 mg/kg	
		Oxyfluorfen	5,000	
		Captan	9,000	
		Ethyl alcohol	13,700	

[1] Oral and dermal ratings are measured in lethal doses (LD_{50}), and inhalation ratings in lethal concentrations (LC_{50}) - the amount of pesticide per unit of body weight that is required to kill 50% of the test animals. These values are only examples of some study results - published values may vary considerably.

Sources: USDA Forest Service (1989); USDA Forest Service (1987); Bohmont (1983) Great Lakes Chemical Company (1989); Thomson (1988)

applied, damaging aerial concentrations of a fumigant should occur rarely, due to the restrictive seal, rapid degradation of the fumigant, and the large volume of air into which it can disperse if it escapes through the seal. However, if the seal is poor or weather conditions prevent rapid dispersion (for example, an inversion layer), toxic fumigant concentrations may build up and injure adjacent plants, animals, or people. Myers (1989) reports that, following MBC fumigation at a forest nursery, an air inversion caused a local accumulation of MBC gases; they had apparently escaped through the tarp and caused minor health effects to residents living near the nursery. Forest nursery managers have reported fumigant damage to adjacent seedlings for both MBC and dazomet. White pines seem to be particularly susceptible to dazomet fumes (Scholtes 1989), whereas Douglas-fir is sensitive to MBC (Myers 1989).

EFFECTS OF FUMIGANTS ON HUMAN HEALTH

All pesticides are poisons, and fumigants are among the most acutely toxic pesticides used in bareroot forest nurseries. It should be remembered, however, that the actual hazard of any chemical is a function of both toxicity and exposure. If fumigants are applied by trained, certified applicators and according to label instructions, the potential health hazards can be

Table 8 - Potential health hazards of common nursery fumigants

Fumigant	Known Health Hazards
Methyl bromide	Exposure Symptoms - Although it has no odor, methyl bromide causes severe chemical skin burns, swelling of bronchial membranes, and kidney damage. Small amounts will cause nausea and vomiting, and may lead to mental confusion, double vision, tremors, lack of coordination, and slurred speech. Continued exposure leads to coma and death.
	Cancer - Variable information.
	Reproductive/Developmental - Organ weight variation in offspring of rats; fetal and maternal toxicity.
Chloropicrin	Exposure Sumptoms - Chloropicrin has an obnoxious odor and was used as a chemical warfare agent in World War I. It is extremely irritating--causing tearing, swelling of bronchial membranes, gasping, and vomiting. Severe exposure may result in irregular heartbeat and asthma.
	Cancer - Insufficient information.
	Reproductive/Developmental - No information.
Dazomet	Exposure Symptoms - Dazomet is irritating to skin and eyes.
	Cancer - None observed in animal studies.
	Reproductive/Developmental - No information on dazomet, but methyl isothiocyanate causes maternal toxicity and fetal death in animals.
Vorlex	Exposure Symptoms - Highly irritating to eyes, skin, and lungs.
	Cancer - Methyl isothiocyanate is not carcinogenic in animals, but 1,3-dichloropropene appears to be.
	Reproductive/Developmental - No information on vorlex, but xylene, one of the ingredients, causes birth defects in animals.

Sources: USDA Forest Service (1989); USDA Forest Service (1987); Bohmont (1984); Thomson (1988); Great Lakes Chemical Company (1989).

reduced to acceptable levels.

All chemicals, including pesticides, can be ranked according to the dose of the chemical required to kill half of a population of test animals; this dose is known as the LD_{50} (table 7). Although oral exposures are most frequently used to determine LD_{50}, other types of chemical exposure are more relevant for fumigants. With all fumigants, there is a risk of inhalation exposure due to their gaseous nature at the time of application or shortly after. Because dazomet is applied as a fine granule, inhalation of granules could be significant as well. There is a dermal exposure hazard with both MBC if skin comes into contact with the pressurized liquid, and dazomet if granules contact the skin.

The common nursery fumigants vary considerably in their toxicity, ranging from the severe to the slight category (table 7).

MBC is the most toxic fumigant used in forest nurseries because chloropicrin ranks in the severe category and methyl bromide is in the moderate category (table 7). Chloropicrin, also known as "tear gas", is extremely irritating to eyes and skin (table 8). Concentrations as low as 2 ppm can be lethal if inhaled for as little as 1 minute, and concentrations of 0.1 ppm can be injurious over longer periods (Thomson 1988). Pure methyl bromide is relatively less toxic than chloropicrin and is rated in the moderate toxicity category (table 7). This fumigant is particularly dangerous to use because it is colorless and odorless. Chronic exposure to methyl bromide causes severe health hazards (table 8); exposure to 2,000 ppm of methyl bromide for 1 hour may be lethal (Thomson 1988). In formulations containing a mixture of methyl bromide and chloropicrin, exposure time to excessive amounts is usually very short; this is due to the extremely irritating nature of the chloropicrin which compels the person being exposed to quickly move from the area. Information about the cancer-causing ability of MB and chloropicrin is varied. For chloropicrin, there is no information regarding carcinogenicity. For MB, some carcinogenic effects are reported (Great Lakes 1989) although very recent reports indicate no cancer effects (Sargent 1989).

Dazomet and vorlex share a common active ingredient (MITC), and rank in the moderate toxicity category (table 7). Dazomet does not break down into a gas until it contacts soil moisture; because of this, it is easier to control than an injected gas. The micro-granule formulation of dazomet can be irritating to skin and eyes (Thomson 1988). Although dazomet has not caused cancer in animal studies, other health effects have been observed (table 8).

Metam-sodium also breaks down into MITC, but is slightly less toxic than dazomet or vorlex, which places it in the slight toxicity category (table 7). Metam-sodium can be irritating to skin, eyes, and mucous membranes (Thomson 1988), but the risk of cancer from exposure to MITC is apparently low (table 8).

Quality of Fumigant Exposure Data

The quality of information on the effects of fumigants on human health is marginal or inadequate in some areas (tables 8 and 9). The published

Table 9 - Quality of nursery pesticide database for each toxicity category.

Fumigant	Systemic	Carcinogenic	Reproductive/ Developmental	Mutagenicity	Neurotoxicity	Immunotoxicity
Methyl bromide	Adequate	Sufficient: new studies could change conclusions	Marginal: variable results	Adequate	Adequate	Inadequate
Chloropicrin	Adequate	Marginal: variable results	Inadequate	Marginal: variable results	Inadequate	Inadequate
Dazomet	Sufficient: new studies could change conclusions	Adequate	Sufficient: new studies could change conclusions	Marginal: variable results	Sufficient: new studies could change conclusions	Marginal: variable results

Source: USDA Forest Service (1989).

information can be categorized by six types of toxicity: systemic, carcinogenic, reproductive and developmental, mutagenicity, neurotoxicity, and immunotoxicity (table 9). Very little work is done on humans; human data is usually derived from accidents or from operational exposure. Therefore, most tests have been done on animals, such as rats or rabbits, and much of the available information is difficult to interpret and compare because different units were used and results were variable. Table 9, however, categorizes the general state of data (adequate, sufficient, marginal, or inadequate) from available published animal studies.

Human Health Risks

When determining the danger of a particular pesticide, both the toxicity of the material, as well as the probablity of exposure, are important. The nursery workers at greatest risk for exposure to fumigants are those involved in applying them: tractor drivers, shovelers, and tarp lifters (table 10). Other nursery workers, such as weeders or inventory crew, will have almost negligble risk since they are in the fields after the fumigant has long since dissipated. For the general public, including residences adjacent to the nursery, there is more potential risk of exposure to fumigants than other pesticides due to the gaseous nature of the fumigants allowing them to diffuse and be carried away from the site of application and onto neighboring property.

The probability that detrimental health effects will occur has been estimated, based on Threshold Limit Values (TLV's), for the various workers involved in fumigant application and for the general public (table 10). A TLV is the estimated maximum concentration for an 8-hour workday exposure that will not result in any adverse effects. Workers using MBC-33 are at the highest risk because their estimated doses for chloropicrin exceed the TLV. Workers applying dazomet are at a lower risk because their estimated doses are less than the TLV (table 10). Risks associated with dazomet application should be further reduced by the lag time between application and formation of toxic compounds in the soil. Gases from both MBC and dazomet can drift for some time after application and may cause workers and neighbors to experience some degree of minor irritation. Although there are not documented cases of serious injury to these people, fumigant drift under certain weather conditions have caused concern (Myers 1989).

FUTURE AVAILABILITY OF FUMIGANTS

For the past few years, nursery managers have expressed concern about the possibility that the use of some fumigants, particularly MBC, will be severely restricted or banned. This is a legitimate concern because other fumigants have been banned after they were detected in groundwater in agricultural areas. A soil fumigant (DBCP) is the most widespread pesticide contaminant of groundwater in the United States, and its use was suspended in 1979. Since then, other fumigants have also been detected in groundwater and subsequently removed from the market: D-D, a nematicide, along with EDB, a close chemical relative of MBC (Russell and others 1987). Because of this "guilt by association," groundwater is being tested across the country for MBC, but it has not been detected as of this date (Parsons and Witt 1989). It is considered unlikely that MBC would ever be detected, however, because it rapidly dissociates into inorganic bromide and a methyl-containing substance before reaching

Table 10 - Probability of health hazards for public and workers exposed to common soil fumigants

		Fumigation Applicators[1]		
Fumigant	Public	Driver	Shoveler	Tarp lifter
Methyl bromide	Low	Moderate	Moderate	High
Chloropicrin	Moderate	High	I[2]	I
Dazomet	Low	Moderate	N/A[2]	N/A

[1] Average exposures per workday, based on historical data of workers not wearing protective clothing.

[2] I = Insufficient information; N/A = Not applicable

Source: USDA Forest Service (1989)

groundwater supplies (Bentson and Lavey 1989).

Another concern about the future of soil fumigants is the possible link to cancer. MBC is particularly suspect because it is considered a possible mutagen in humans (USDA Forest Service 1989), and the closely-related EDB has already been shown to be a potent carcinogen in animals (Russell and others 1987). Although further cancer testing is underway for both methyl bromide and chloropicrin, the results are inconclusive so far (USDA Forest Service 1989).

At the present time, however, none of the four currently used fumigants (MBC, dazomet, metam-sodium, or vorlex) are in any danger of losing their pesticide registration in the United States. We specifically inquired about the re-registration status of the MBC fumigants and company representatives and EPA scientists informed us that they will continue to be available to the agricultural community (Andersen 1989).

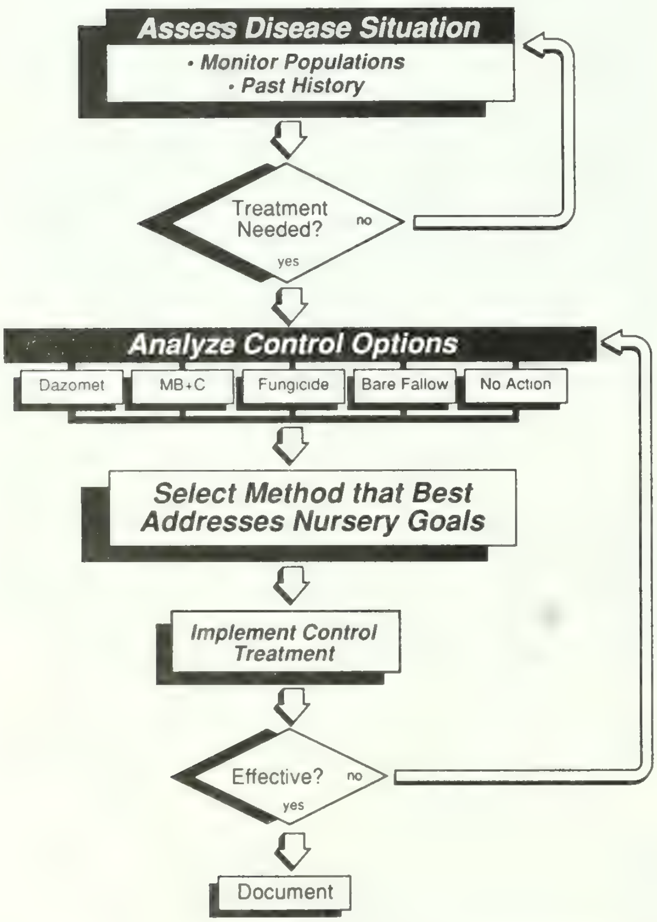

Figure 7 - A flow chart can help nursery managers think through the sequential steps in a integrated pest management (IPM) program. This example shows the sequence of events for managing a soilborne disease problem.

CONCLUSIONS AND RECOMMENDATIONS

Although fumigants are extremely toxic pesticides, they are relatively not persistent in the environment, they have immediate severe health risks, but long-term risks are not much more severe than other pesticides. If properly applied with adequate precautions, they can continue to be a major weapon in the chemical arsenal.

Fumigation and Integrated Pest Management

Soil fumigation, along with other cultural activities and pesticides, should always be viewed in the larger context of an overall nursery pest management plan. Progressive nurseries have begun to define their pest management activities in the context of Integrated Pest Management (IPM). IPM in forest nurseries can be defined as:

> "Integrated nursery pest management is the maintenance of seedling pests at tolerable levels by the planned use of a variety of preventive, suppressive, or regulatory methods (including no action) that are consistent with nursery management goals. It is implicit that the actions taken are the end-result of a decision-making process where pest populations and their impact on hosts are considered and control methods are analyzed for their effectiveness as well as their impact on economics, human health and the environment" (USDA Forest Service 1989).

Use of a fumigant, like any other pest control method, must be analyzed for the entire range of nursery effects:

* control of the target pest
* impact on seedling growth and survival
* cost of application
* effect on the environment
* hazard to worker health and public safety.

Selection of a pest control method to control a specific target pest will depend on the priorities and resources of the nursery. Pesticides are no longer applied based solely on their ability to control a pest or because they are considered to be more cost effective than other methods. Other issues, such as risk to human health, may drive the decision to use or not use a particular pest control method.

The decision-making process for managing soil-borne pests in a forest nursery can be illustrated with a flow chart which shows both the steps and the order in which they are taken (fig. 7). In this flow chart, there are several key steps:

1. Determining whether or not there is a pest problem in need of treatment

2. Deciding which pest control methods are available to reduce or prevent crop damage

3. Analyzing the benefits and drawbacks of each method

4. Selecting the best pest management method in accordance with the goals and priorities of the nursery

5. Implementing pest treatment

6. Evaluating the treatment for effectiveness

Documentation is an important yet often neglected part of an IPM program. Adequate documentation includes figures on pest population trends, type of control treatment (what was used, rates, dates of application, etc.), and treatment effectiveness, but there should also be some documentation of the analysis and rationale used for selecting the treatment to aid in future decisions.

If fumigants are analyzed and applied in a comprehensive IPM context, nursery managers can be assured that they are acting in a logical, environmentally sound manner and will continue to be able to use these effective pesticides.

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Effects of Fumigation on Soil Pathogens[1] and Beneficial Microorganisms

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Abstract.--Soil fumigation with broad-spectrum biocides is a non-selective means of killing soil-borne pathogens in forest seedling nurseries. Beneficial microorganisms (antagonists, competitors, pathogen parasites and mycorrhizal fungi) are also killed by most fumigants. Organisms are killed by direct contact with fumigants. Dormant structures of microorganisms are usually more resistant to fumigant action. Specific fumigants are more effective against certain microorganisms. Fumigant effects on populations of selected pathogens (*Fusarium*, *Pythium*, *Phytophthora*, *Rhizoctonia*, *Macrophomina*, and *Phoma*) and certain antagonistic fungi, bacteria, and mycorrhizal symbionts are discussed.

INTRODUCTION

Using soil fumigation to control soil-borne diseases has recently increased in importance at many forest tree seedling nurseries in the United States. Techniques using broad-spectrum soil fumigants to enhance plant production by reducing impacts of pathogenic fungi were first developed for agricultural crops (Miller and Norris 1970). Operational soil fumigation over a relatively large area was probably first successfully used for strawberry production in California (Wilhelm and others 1974). Techniques and products developed for agriculture have been implemented at many forest tree nurseries. Soil fumigation has usually improved the number and quality of seedlings produced (Klock and Benson 1975; Norris 1983; Norris and Hessburg 1985; Smith and Bega 1966) while reducing weeds and soil insect problems.

Over the years, several chemicals have been tested for use as soil fumigants. However, consistent beneficial effects have only been obtained with a few products and formulations (Munnecke and Van Gundy 1979; Wensley 1953). Combinations of several different fumigants are often more effective than single chemicals (Smith and Bega 1966), as is the case with methyl bromide and cholorpicrin (MBC). MBC is the most commonly used fumigant combination for forest nurseries, and although different formulations have been tested, the most popular and effective solution for controlling soil-borne pathogens is 67 percent methyl bromide and 33 percent chloropicrin. Most fungi are more susceptible to cholorpicrin mixtures than the methyl bromide alone (Ebben and others 1983; Munnecke and Van Gundy 1979). Other fumigants used less frequently include metam-sodium (Vapam®) and dazomet (Basamid®).

All fumigants kill soil microorganisms non-selectively through direct contact (Boone 1988). Susceptibility of microorganisms to fumigants is variable, especially at reduced or "sub-lethal" dosages. However, all microorganisms are susceptible if fumigant concentrations are high enough. Fumigant action is largely affected by soil temperature, i.e., most chemicals are more effective at higher temperatures (Gandy and Chanter 1976).

ECOLOGY OF SOIL MICROORGANISMS

Nursery soil is an extremely conducive habitat for a variety of microorganisms. Their relative numbers may fluctuate widely and are greatly affected by season, cropping history, and types of amendments. Normally, microorganisms interact with each other and compete for substrates. Many pathogenic fungi are rapid initial colonizers of suitable substrates, such as host roots. This provides them a better competitive position since many do not compete well with more free-living, saprophytic soil organisms (Papavizas 1985).

Most soil organisms are either actively colonizing substrates or dormant. Substrates are colonized by a succession of organisms. As indicated above, pathogens often are initial colonizers and are followed by other organisms that are better competitors. Competition by soil microorganisms is often intense; many are capable of producing powerful antibiotics which give them competitive advantages (Papavizas 1985), while some parasitize other organisms. Another competitive advantage is rapid spore germination and growth when new substrates become available.

Many pathogens produce dormant "resting" structures which are stimulated into activity by presence of a suitable host. Roots of most plants exude amino acids which may stimulate germination of spores as well as provide directional gradients for motile spores and growing hyphae of certain pathogenic fungi (Rovira 1970). Most dormant structures are fairly long-lived and resistant, although they respond readily to

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host root exudates and may be susceptible to damage by biocides like soil fumigants.

FUMIGATION EFFECTS

General

Most soil fumigants are non-selective in their action against microorganisms, but rarely are all organisms killed during standard treatments. Organisms tightly bound in soil aggregates and those deeper in the soil below the zone of effective fumigation (greater than 25-30 cm) may escape undamaged (Fuller and others 1980; Kolbezen and others 1974; Marshall 1985). Some investigations (Baines and others 1966; Ebben and others 1983) found that different organisms have different sensitivities to commonly used fumigants. These tests were usually done at lower fumigant concentrations. Most of these investigations showed that microorganisms which produce more resistant dormant structures (such as fungal sclerotia) are more resistant to fumigants.

Once fumigated, soil is conducive to rapid reinvasion by microorganisms (Danielson and Davey 1969; Munnecke and Van Gundy 1979). A "biological vacuum" may occur and any organism initially introduced into fumigated soil often expands rapidly to produce abundant populations because of the lack of competition from other organisms. Fumigation also releases an abundance of nutrients (from death of previous organisms) which may provide an important source of growth substances for invading organisms (Munnecke and Van Gundy 1979). Organisms commonly reinvading fumigated soil produce air-borne propagules, are located deeper in the soil, or reside within adjacent non-treated fields (Danielson and Davey 1969). Important re-invaders may also be introduced on seed, nursery implements, or in water.

Effectiveness of soil fumigation is often monitored by assaying for selected microorganisms before and after fumigation (Johnson and Zak 1977; Marshall 1983). The two most common genera of fungi assayed are *Fusarium* and *Pythium*. Soil dilutions on selective agar media are made and the number of propagules (colony forming units) per unit weight of soil (usually grams) are calculated. These assays are for total populations of these fungi and do not necessarily determine levels of pathogens. There are pathogenic and saprophytic strains of both *Fusarium* and *Pythium*. Therefore, it may be difficult to correlate soil populations of either of these organisms with disease (Bloomberg 1965), although predictions of losses based on soil assays are sometimes made (Hildebrand and Dinkel 1988). Further, most soil assays do not include levels of potential antagonists (such as bacteria, Actinomycetes, *Trichoderma*, etc.). Levels of these competitors may be more important in predicting disease than the levels of *Fusarium* and *Pythium* in the soil (Marshall 1983; Papavizas 1985).

Effects on *Fusarium*

Fusarium spp. are widely diverse fungi which are very important plant pathogens (Nelson and others 1983). Although important pathogens of agricultural crops and forest seedlings in nurseries (Sutherland and others), *Fusarium* spp. are not often pathogens in natural forest stands. In soil, most pathogenic species of *Fusarium* produce dormant structures called chlamydospores. However, species which do not normally produce chlamydospores produce other resistant-type structures in the soil (Hargreaves and Fox 1977). Most chlamydospores, other types of spores (macroconidia) and other resistant structures are fairly long-lived in the soil; their longevity depends on level of microbial antagonism and presence of suitable host substrates. Chlamydospores germinate when stimulated by host root exudates (Rovira 1970). Rapid colonization of host material after spore germination is important for this group of fungi.

Fusarium spp. are generally reduced by soil fumigation (Gillman 1977; Roberts and others 1988). However, they are less sensitive to some fumigants, such as methyl bromide, as some other fungi (Ebben and others 1983; McCarter and others 1978; Munnecke and others 1978; Norris 1986). Dry macrocondia (Weststeijn 1973) and mycelium (Munnecke and others 1978) may be quite resistant to fumigants. Metam-sodium may (Corden and Young 1965) or may not (Ben-Yephet and Frank 1985; Campbell and Kelpsas 1988) be as effective as MBC in reducing *Fusarium* levels. Dazomet reduces *Fusarium* levels in soil, but usually not as effectively as MBC (Campbell and Kelpsas 1988). Surviving propagules may quickly reinvade dazomet treated soil (Hoffman and Williams 1988). Vorlex® (methyl isothiocyanate and chlorinated hydrocarbons) did not significantly reduce numbers of *Fusarium* propagules in two studies (Manning and Vardaro 1977; Sinclair and others 1975). However, in another study (Marois and others 1983), this fumigant eliminated *Fusarium* from the top 20 cm of soil, although the pathogen quickly reinvaded fumigated soil from below.

Except in dazomet treated soil, *Fusarium* spp. may be rather slow recolonizers of fumigated soil (Danielson and Davey 1969; Johnson and Zak 1977). However, if introduced on seed or from adjacent non-fumigated fields, these fungi may increase to levels higher than those found before fumigation (Young 1940).

Effects on *Pythium* and *Phytophthora*

Pythium and *Phytophthora* are two very important plant pathogens. These "water molds" produce motile zoospores which move through soil in water and seek out host roots to infect. As such, they are usually more damaging in poorly drained soils. They can inhabit water supplies and be introduced through irrigation water. Many agricultural crops and forest seedlings in nurseries are attacked by these fungi (Sutherland and others 1989).

Dormant structures of *Pythium* and *Phytophthora* are either asexual (sporangia and chlamydospores) or sexual (oospores). These thick-walled spores can remain viable in soil for extended periods of time and withstand periods of desiccation. When soil moisture is adequate, sporangia will germinate to produce zoospores capable of attacking plant roots. Oospores and chlamydospores germinate to produce a mycelium that may grow toward host roots in response to root exudates (Rovira 1970).

Pythium and *Phytophthora* are more sensitive to most fumigants than several other plant pathogenic fungi (Gillman 1977; Munnecke and others 1978; Norris 1986). Their mycelium is readily killed by fumigants, even at relatively low concentrations (Roberts and others 1988; Smith and Bega 1966). Oospores and chlamydospores are probably the most resistant to fumigant action, but at concentrations usually employed at forest nurseries, they are readily killed as well (Munnecke and others 1978). One problem in controlling these fungi with fumigation is the rapidity with which they reinvade treated soil (Campbell and Kelpsas 1988; Johnson and Zak 1977; Tkacz 1983; Vaartaja 1967). Reinvasion may occur from large populations existing

below the zone of fumigation and/or through irrigation water. Experience indicates that they are usually detected in higher numbers than *Fusarium* in recently fumigated soil (Tkacz 1983). Dazomet is more effective in reducing populations of *Pythium* than *Fusarium* (Tanaka and others 1986).

Effects on *Rhizoctonia*

Rhizoctonia solani is an important pathogen of many agricultural crops and causes damping-off of conifer seedlings in nurseries (Sutherland and others 1989). This organism is well adapted to the soil environment. For example, it rapidly colonizes organic material introduced into soil before many other organisms, and it is rather resistant to microbial competitors. *Rhizoctonia* is also capable of producing sexual spores (basidiospores) which may be disseminated long distances in air or water.

Rhizoctonia is usually more sensitive to fumigants than *Fusarium*, but less sensitive than either *Pythium* or *Phytophthora* (Munnecke and others 1978), although responses of *Rhizoctonia* spp. are not often assayed in nursery soils (McCarter and others 1978; Smith and Bega 1966).

Effects on *Macrophomina*

Macrophomina phaseolina causes charcoal root disease of several conifer species in forest seedling nurseries (Smith 1975). The fungus produces abundant sclerotia which may remain viable in the soil for long time periods. The only effective way of reducing these soil propagules is by fumigation, particularly with MBC (Cordell 1982; Rowan 1981; Smith and Bega 1966).

Effects on *Phoma*

Phoma comprises a diverse group of soil-borne fungi that attack a wide range of host plants. Most species are considered relatively weak pathogens, but some *Phoma* spp. can cause serious root and stem rots and tip dieback of bareroot seedlings (James and Hamm 1985). Most species produce several spore stages; dormant structures in soil are either chlamydospores or dictyochlamydospores. On suitable substrates under moist conditions, *Phoma* spp. produce sporophores called pycnidia which ooze spores capable of moving in the soil.

Assays for *Phoma* in fumigated soil are not usually conducted. However, experience with styroblock containers indicates that these fungi may be difficult to kill with standard sterilants (James and Woollen 1989). It is likely that most fumigants, especially MBC at dosages normally employed, effectively kill most propagules of *Phoma* in nursery soil.

Effects on Beneficial Microorganisms

Bacteria

Many diverse groups of bacteria commonly inhabit nursery soil. Several species are antagonistic toward common soil-borne pathogens (Cornwall 1985). Some soil bacteria form dormant spores relatively resistant to environmental degredation. Some species, such as *Bacillus*, may produce spores resistant to fumigants, at least at low chemical concentrations (Altman 1970). Bacteria are also very rapid recolonizers of fumigated soil (Ingestad and Nilsson 1964; Martin 1963; Wensley 1953).

Actinomycetes

This group of primitive fungi are common soil inhabitants and many species are antagonistic toward other soil fungi (Cornwall 1985). Members of this group may remain dormant in the soil for long periods of time; however, most members are readily killed by commonly used fumigants. They will reinvade fumigated soil, but slower than some other types of fungi (Cornwall 1985).

Trichoderma

Trichoderma spp. are common soil-borne fungi that reside in many soil types, including those from forest nurseries (Papavizas 1985). They exist saprophytically on a wide variety of organic substrates, readily competing with or being antagonistic toward many plant pathogenic fungi, including *Fusarium*, *Pythium*, *Phytophthora*, and *Rhizoctonia*. Some species of *Trichoderma* produce powerful chemicals toxic to other fungi; other species are parasitic on certain groups of soil fungi (Papavizas 1985). *Trichoderma* spp. are usually less sensitive to common soil fumigants than many soil-borne pathogens (Gandy and Chanter 1976). These fungi are often the first to be detected at high levels after soil fumigation (Danielson and Davey 1969; Ingestad and Nilsson 1964; Vaartaja 1967; Wensley 1953), often reaching higher population levels than in nonfumigated soil (Marshall 1986; Martin and Pratt 1958; Sinha and others 1979; Vaartaja 1967). *Trichoderma* often is the dominant microorganism in fumigated soil (Bollen 1961; Martin and others 1957; Warcup 1957).

Endomycorrhizal Symbionts

Endomycorrhizal fungi are important in production of many hardwood tree seedlings. They are not disseminated readily because their spores are soilborne. Most endomycorrhizal symbionts are quite sensitive to fumigants and are readily killed at concentrations normally used. These fungi are more sensitive to low doses of methyl bromide than many soil-borne pathogens (Menge 1982), although not all propagules are usually killed, especially those below the zone of effective fumigation (McGraw and Hendrix 1984). Endomycorrhizal fungi are usually very slow to infest fumigated soil because of their subterranean sporulation (Menge 1982). Growth depression of crop plants following fumigation has been at least partially due to reduction of endomycorrhizal inoculum in the soil (Munnecke and others 1978; Wilhelm and others 1974). In cases where endomycorrhizal fungi are necessary for satisfactory production of seedling stock, they must be reintroduced manually following fumigation.

Ectomycorrhizal Symbionts

Ectomycorrhizal fungi, common inhabitants of conifer seedling nurseries, are usually reduced the first year following fumigation, but often return to pre-fumigation levels the second year (Johnson and Zak 1977; Peterson 1970). Although most ectomycorrhizal fungi are susceptible to most fumigants, Rowan (1981) reported that *Thelephora terrestris* is somewhat resistant to MBC because fumigation did not affect soil-borne inoculum of this species. Ectomycorrhial fungi were not significantly reduced in Vorlex® treated soil (Sinclair and others 1975). Although retardation of mycorrhizal formation may occur in fumigated soil, seedling response may still be greater than in non-fumigated soil because of reduced pathogen levels (Hacskaylo and Palmer 1957; Laiho and Mikola 1964). Ectomycorrhizal fungi are readily disseminated by air-borne spores and usually reinfest fumigated soil if there are large conifer trees near nurseries or if adjacent fields harbor inoculum (Cordell 1982).

In cases where inoculum is not readily available, these fungi may have to be reintroduced manually following soil fumigation.

CONCLUSIONS

Communities of soil microorganisms tend to stabilize quantitatively and qualitatively in the absence of biocides that may preferentially inhibit certain species. When susceptible hosts are introduced into soil, certain pathogens may proliferate unless restricted by the action of competitors or antagonists. As indicated earlier, spores of pathogens are stimulated into activity by the presence of host roots. However, if resident populations of antagonists are sufficient, pathogens may not be able to cause disease. Over time, pathogens and competitors/antagonists tend to come into "balance" and will remain so until that balance is upset. Several factors can upset this balance, including introduction of extensive amounts of susceptible host material, introducing pathogen populations (such as on seed), and treatment of soil with biocides.

Because most fumigants are non-selective in their action, their use results in a soil habitat colonized most by the organisms first reintroduced following treatment. If these initial colonizers are "good" fungi, i.e., those competitive with or antagonistic toward pathogens, any pathogenic fungi inadvertently introduced will not proliferate and little disease will likely result. Conversely, if pathogens are the first to be reintroduced into fumigated soil, such as on seed, they will proliferate and reach higher levels than before fumigation and disease losses could be extensive. One problem with soil fumigation is that once this practice is implemented, it usually has to be repeated before each successive crop because the biological balance of microorganisms in the soil has been disrupted.

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Soil Fumigation at J. Herbert Stone Nursery[1]

John R. Scholtes[2]

Abstract.--A brief discussion of the history, and current fumigation operations and experiences at the J. Herbert Stone Nursery. Also a post script to this presentation.

INTRODUCTION

The J. Herbert Stone Nursery (JHSN) was established Through a joint effort between the USDA Forest Service and Bureau of Land Management. The site was obtained in two purchases in 1976 and 1982. It is administered by the Rogue River National Forest. The nursery is located in Southwestern Oregon near the towns of Central Point and Medford, Oregon. The total area of the Nursery site is 306 acres with approximately 213 acres of seedling production area. Douglas-fir makes up approximately 60% of the production although a total of 18 - 22 species are produced each year.

The climate is described as "mediterranean" having hot-dry summers, a long growing season and wet-mild winters. The established lifting window for the "dormant plant" lifting season is between December 1st and March 1st.

Most of the nursery's clients are made up of several National Forests and Bureau of Land Management Districts within the southwestern quarter of Oregon and the northern portion of California. Some specialty products such as 1-0 Western larch are being produced for clients as far away as Northern Idaho and Western Montana.

Age classes being grown include both 1-0 and 2-0 ship seedlings with a minor but increasing number of 1-1 transplant seedlings being ordered. These different species and age classes are further divided into a complicated array of "cultural groups" in order to custom grow seedlings which meet the different morphological characteristics requested by the clients while still producing plants that are phenologically sound for lifting, handling and transplanting. The "target seedling" concept has been used for several years to establish the range in options which are available to clients have when ordering seedlings.

PAST EXPERIENCES WITH FUMIGATION

Soil fumigation has been a standard part of the nursery production program since the first seed was sown in the spring of 1978. The original fumigant used was a mixture of 67% methyl bromide and 33% chloropicrin (MB-C). This material was applied and covered with plastic tarp in the standard manner. It was always applied by a fumigation contractor. Fumigation was generally done in the fall before sowing. There have been small areas fumigated in the spring when there were seedlings still occupying areas designated for sowing the following spring. In these cases, the seedlings were removed during the winter lifting season and the fumigation was completed as soon as the soil was in acceptable condition that spring.

Fumigation has always been done for the control of soil born pathogenic fungi which are known to cause pre and post germination dampening-off as well as root rot during later plant development. The pre and post fumigation soil tests have consistently shown that MB-C is a highly effective fumigant for the pathological fungi which were considered threatening at this site.

However, there has been an increasing concern over the continued use of MB-C. This concern has developed from several factors. There has been rumors that MB-C may be more stringently regulated or even banned from use. There have also been rumors about tighter controls on the disposal of the tarp and other materials which have been in contact with the chemical. One nursery had an incident involving this material as well as other factors which led to an administrative decision to ban the use of the product at that site. Recent experiences with poor contractor safety and performance at JHSN has also been a major factor in searching for an alternative product.

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[1]Paper presented at Intermountain Forest Nursery Association Annual Meeting. [Bismack, North Dakota, August 14-17, 1989].
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The development of a new formulation of the fumigant dazomet known as Basamid[R] spurred the Nursery Management and the Forest Pest Management people in the Forest Service Regional Office in Portland, Oregon to look into the use of this new product as a nursery fumigant. Several tests have been conducted at JHSN over the past several years.

The first test involved several small plots in a single seedling bed. Different levels of dazomet were incorporated into plots. pre and post fumigation soil analysis was done to evaluate the effectiveness of the material. Seedlings were also grown in these plots and evaluated. The data was very encouraging so the following year, an area of approximately one acre was not fumigated with methyl MB-C. The standard fumigation layout in this field required that fumigation be done perpendicular to the way the seedbeds run. Therefore, the area left untreated ran across an entire field of seedbeds. This area was later treated with dazomet. pre and post fumigation soil samples were taken for both fumigants for laboratory analysis by FPM personnel. The area was sown to several species of seedlings involving many different seedlots. The soil samples proved that, while the dazomet was not quite as thorough as the MB-C, it still performed within the ranges considered to be effective. Informal evaluation of the seedlings growing in the two treatment areas did not detect any differences.

The following year, about half of the ground to be fumigated was treated with dazomet. Again, no differences in effectiveness nor seedling characteristics were noted.

In the fall of 1988, the entire area to be fumigated was treated with dazomet. All went well for several days after the treatment. Then it was discovered that both 1-0 and 2-0 Western white pine in a field east of the treated area was starting to exhibit signs of chemical injury to the needles. The affected needles turned straw yellow to reddish brown within a period of one to three days from the first indications of trouble. This was quite a surprise to the management of JHSN. Up to this point, there had been no indication of trouble with seedlings in areas adjacent to areas treated with this product. There had been discussion with another nursery about observed trouble when it was applied near Western white pine. However, it was thought that being across a major field road which was a distance of over fifty feet would be sufficient to afford protection from any chemical or gaseous drift. In this case, the JHSN damage extended well over 200 feet into the seedbeds with occasional damage over 300 feet into the beds. The damage seemed to be quite selective. Even though there was a gradient of damage from heavy near the fumigation site to minor at a distance of 250-300 feet away from the treatment boundary, there was also a distinct pattern of individual seedlings. Near the treatment site, certain individuals would have 90-100% needle kill while neighboring seedlings would show only minor tip burn. Further away, there were seedlings with one half the length of nearly all their needles burned while adjacent seedlings showed no symptoms.

This event also surprised the chemical dealer and manufacturer. They had been involved with the JHSN testing and use from the very first tests. The application of the chemical had even been video taped at the JHSN location as a demo on how to apply it on a large scale operation.

Having experienced this event, the management of JHSN is looking at how to prevent a similar occurrence in the future. It is felt that this is an effective alternative to the use of MB-C and its continued use is justified. Proper precautions, however, must be taken when it is used in areas near plants which are apparently susceptible to it or its by-products.

The reasons for this incident and the causal agents have been discussed at length. We are virtually certain that the problem was not caused by drift of the product during application. The application was done under carefully monitored conditions and the damage did not appear for some days after application. It was noted that there had been a weather incident after the application during which there had been particularly still mornings. This is not unusual in the Rogue River Valley in which the nursery is located. This type of condition, known as an air inversion, traps air in the entire valley but is also noticeable within local areas of the valley when ground fog lays just a few feet off the ground and there is no noticeable movement of the local air. It is conjectured that such a condition led to the buildup of escaping by product gasses from the dazomet into some level of concentration at or near the ground surface. This concentration could have then moved slowly down drainage across the area of Western white pine. The affected area was located at a lower elevation than the treated area and the pattern of damage supports this idea.

Future use of this product must be more carefully planned. Among the measures being considered at this time include: Treating smaller areas within a given time frame (approximately 20 acres had been treated in one application day in the case of the damage to the Western white pine). Perhaps treatment with another fumigant should be used when the area is near the susceptible species. Better sealing techniques may be required such as using plastic. The weather patterns may be more carefully monitored to avoid still air and inversion conditions. Other more radical treatments have also been considered. Using a fan system such as used for slash burning or orchard frost protection may provide the air movement needed to prevent damage to susceptible species. A barrier such as a plastic covered fence may detour the air around the area to be protected. There may be other methods of protection as well.

A POST SCRIPT TO THE PAPER

Dazamet was used again in the fall of 1989. Prior to treatment, a few methods of protecting Western white pine seedlings which would again be near the treated area were evaluated. A barrier

of plastic over shade frames was placed down slope between the Western white pine and the treatment area. Smoke from torches was released on the treatment side of the barrier on a "still" morning. The smoke simply built up and crawled over the 4-5 foot high fence. A large gas powered fan used to fire piles of forest logging slash was placed in different positions around the barrier. This offered little or no protection as the smoke went over, around, and past the fan.

Finally, it was decided that the only protection that could be counted on was distance or being totally down wind from susceptible species. A small contract was let to use MB-C adjacent to two areas of Western white pine. One area adjacent to Western white pine transplants was completely treated with MB-C. The other area was treated for a distance of 250 feet from the Western white pine. The results were that the area totally treated with MB-C has no noticeable affects from the fumigation. However, the Western white pine that was within 250 feet of the dazamet was again seriously affected. This time, no affects were observed for several days after treatment. Then, after another heavy-still morning, the needles on the Western white pine started turning. Again, a definite pattern is noticeable across the area of seedlings. A portion of the area which is at the same elevation or higher that the treated area had no damage. The damage also grades out as the distance from the treated field increases. There is again, a noticeable difference between damage to individual seedlings adjacent to each other.

THE FUTURE

The old adage "if he does it to me once, shame on him - if he does it to me a second time, shame on me" is beginning to nag at the management at JHSN. We know that dazamet is a useful tool and a good alternative to using MB-C. We feel that we need to keep both of these chemicals available for selective use as needed. The fact that Western white pine can be damaged when dazamet is used in the vicinity attests very strongly to the need for alternatives. We had sown the two age classes of Western white pine involved in this damage in the center of the nursery not anticipating any problems. Last spring (1989) we located the Western white pine in an area of the nursery which is up drainage and generally upwind from any other field at the nursery. We will continue to locate this species into areas which are not susceptible to the downwind or down drainage conditions which led to the damage of the past two seasons. In addition, we will be looking very hard at using MB-C in any area that is within 500 to 700 feet of Western white pine seedlings. We know now that preventive steps must be extra ordinary. The 250 foot buffer was simply not sufficient.

We have also been working on other treatments to give us additional tools in the fight against pathogenic fungi. We have participated with several other nurseries in a contract with a local University to study fusarium. This work has shed some light on management options which may one day help control this pathogen. Other treatments and management techniques will be evaluated in the future as organic methods become better understood and alternatives to chemical control are developed.

Methyl Bromide Fumigation at the Lone Peak State Forest Nursery, Utah[1]

David G. Grierson[2]

Abstract.--Methyl bromide-chloropicrin fumigation has been done at the Lone Peak State Nursery by staff members, which gives much more flexiblilty ot the process and ultimately, better control. The primary reason for fumigation at the site is for the control of weed and weed seed, and fumigation is an integral and strategic part of the long-term weed management plan.

BACKGROUND

The Lone Peak State Forest Nursery, located in Draper, Utah, has been on its present site for nearly 15 years. Prior to the nursery being located there, the site had been used for alfalfa hay and pasture and had then spent considerable time unused. As a result, a tremendous reservoir of weed and weed seed had built up, with a nearly unmanageable diversity of weed species. Additionally, the lack of shelterbelts around the nursery and a notorious, ever-present prevailing wind brought more weeds and weed seeds by the bucketfuls.

NURSERY DEVELOPMENT

Back in the mid 1970's pressure from management would not allow proper development of the nursery. Production of seedlings was paramount for the governor's "Million Trees for a Million People" program while sound nursery cultural practices fell by the wayside. In 1979, it was decided that the weed problem had top priority and finally a plan was set up to deal with the problem.

Fumigation was contracted out in 1980 on a trial basis and the results were mixed. Problems with contractor scheduling, wind, and soil moisture gave marginal results in some areas, and great weed control in others. It was great when it worked, but when it did not, it was costly.

The greatest problem encountered was the problem of contractor scheduling. The amount of fumigation done annually at the nursery is 4 to 6 acres which does not give contractors much profit motive to make a special trip to Salt Lake City. If they do decide to make the trip it was usually a stopover between Luck Peak Nursery and Mt. Sopris Nursery and contractors gave themselves a fairly narrow window for fumigating.

In 1983, an opportunity to purchase a used fumigator presented itself. The cost was $4500, from a contractor who just wanted to get out the business. The Lone Peak State Forest Nursery hired a consultant from North Carolina, Clarence Lemon, to assist in the start-up, safety and training in methyl bromide fumigation. The staff at the nursery has been fumigating the production blocks ever since.

The supplies needed for fumigation include: fumigant (67% methyl bromide, 33% chloropicrin), sprayable glue, 1 mil poly tarp and nitrogen to pressurize the fumigant tanks. The per acre cost of supplies are currently running about $700. Other cost include maintenance costs for hoses, and fittings.

[1]Paper presented at Intermountain Forest Nursery Association Meeting, August 14-17, 1989.

[2]David G. Grierson is Nursery Manager, Lone Peak State Forest Nursery, Draper, Utah.

RESULTS

The biggest advantage the nursery has with doing its own fumigation is the flexibility in the control of weeds. For fall fumigation, the dates can be moved back as late as weather and soil temperatures permit, minimizing the late summer blow-in of weed seed. There also have been times when spring fumigation occurred when fall fumigation was unsuccessful.

Generally fumigation is done in the early morning before the afternoon winds begin to pick up. Morning fumigation allows the soil moisture to condense on the tarp under the heat of the sun. This allows added weight to the tarp to resist effects of the wind.

The weed control at the nursery is worth the time, effort and money. In 1986, funds were not available for fumigation and the results were disastrous. Conifer losses were up by 60% and hardwood production suffered similar losses.

Fumigation is an integral part of the nursery weed management plan. The future of fumigation is stable at the Lone Peak State Nursery although eventually it will be reduced to once every second or third rotation.

Because the nursery staff is trained to do its own fumigation the efficiency has been increased. The flexibility of scheduling and reduced lobor costs make up for the increased hassle. The costs to the beneficial soil borne micro-organisms may be high right now, but the benefits received as a result of the weed control outweighs that cost right now. The weeds sap more from the seedlings than the micro-organisms can contribute.

Dazomet Use for Seedbed Fumigation at the PFRA Shelterbelt Centre, Indian Head, Saskatchewan[1]

Lyle K. Alspach[2]

Abstract.--Testing was conducted at the Shelterbelt Centre to allow selection of a suitable fumigant for use in bareroot conifer seedbeds. The major concern was control of damping-off; weed control was secondary. Results of the trials, product handling hazards and ease of application were considerations when final selection took place. The chemical of choice was dazomet and the product currently in use is Basamid. The effectiveness of this product is dependent on careful adherence to application instructions.

INTRODUCTION

Bareroot conifers and hardwoods are produced at the PFRA Shelterbelt Centre, Indian Head, Saskatchewan. The trees go to clients throughout the prairies: primarily in Manitoba and Saskatchewan. Annual production ranges between seven and ten million, of which eight hundred thousand are conifers.

Dazomet is the fumigant currently used to control soil fungi in both the conifer and shrub seedbeds. It was tested in eight trials, over a number of years, at Indian Head. Few problems have been encountered, however, weed control has been inconsistent. Control of soil-borne fungi, especially those which cause damping-off, has been good.

DAZOMET TESTING 1963 - 1969

Dazomet, along with other soil fumigants, was tested during a six year period. Conifer species included Colorado spruce, white spruce and Scots pine.

The first two trials involved testing of dazomet, metam sodium, methyl bromide and allyl alcohol. This number was further reduced to include only damomet and metam sodium in four subsequent trials.

Summaries for the first two trials do not clearly outline the procedure used for fumigant application (ie. application method and incorporation) Morgan (1963 and 1964). The plots were irrigated after treatment and a waiting period of two to three weeks was allowed between application and sowing.

Allyl alcohol at 110-225 litres per hectare and metam sodium at 170-505 kg/ha provided excellent weed control with good conifer germination. Dazomet at 110 kg/ha provided poor weed control one year, excellent the next. At 225 and 335 kg/ha it provided fair weed control one year, excellent the next. Further to this variability, the stand of Colorado spruce and Scots pine was reduced by the two higher rates the first year, but not the second. Methyl bromide application rates seemed to be excessively high, based on current application rates at several nurseries. They ranged from 490 to 1465 kg/ha and this could account for the reduced conifer stands in the first trial. Seedling vigor and growth, in the second year trial, was generally greater in handweeded checks, than in fumigated plots. This could be attributed to reduced seedling density resulting in greater water and nutrient availability per check seedling. Similar conclusions have been drawn by Campbell and Kelpsas (1988).

Due to a concern over the acute toxicity and handling hazards of methyl bromide and the lack of availability of contract applicators, a decision was made to eliminate it from future trials and to concentrate on dazomet and metam sodium.

Rates of testing for metam sodium were initially 170 to 505 kg/ha, later increased to 240 to 575 kg/ha. The range of dazomet rates was increased from 110 to 335 kg/ha initially to 110 to 450 kg/ha. Application methods were inconsistent as summaries indicated that sometimes only irrigation was used for incorporation and sealing; on one occassion the metam sodium was injected and the dazomet was incorporated by tillage; on two occassions the plots were covered, once using burlap and once with polyethylene. The one consistent aspect of all

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[1]Paper presented at the Intermountain Forest Nursery Association Annual Meeting (Kirkwood Motor Inn, Bismark, N.D., August 14-18, 1989).

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the fumigant treatments was the application of irrigation, following treatment, to seal the soil surface.

Weed control in the fall fumigated, spring sown Colorado spruce and Scots pine seedbeds ranged from satisfactory to excellent. Weed control results in the fall sown white spruce were not as good. This could possibly be attributed to the longer period between treatment and the next growing season. The period between treatment and sowing was shorter than for Colorado spruce and Scots pine, but it is unlikely that would have a negative effect on weed control.

All of the fumigant treatments, with one exception, increased emergence and reduced seedling losses, due to damping-off, as compared to the handweeded checks. The single exception was the high rate of dazomet, in one trial, which failed to increase the emergence of Scots pine and white spruce over that in the handweeded check.

Additional Trials 1972 and 1978

Dazomet was adopted for use at the Shelterbelt Centre based on results of the preceding trials and on ease of handling and application. After a few years use, a couple of additional trials were conducted: one to assess polyethylene covered versus non covered plots and one to assess two product formulations, Mylone (50D) versus Basamid (98G) Anonymous (1972 and 1978). Weed control was better in plots where a polyethylene cover was used to provide a seal during treatment than in non covered plots. There was no difference in results between the two product formulations.

OPERATIONAL DAZOMET APPLICATION AT THE SHELTERBELT CENTRE

Application Equipment

As practical experience was gained in the use of dazomet, a refinement in application equipment took place. Originally a 'Gandy' granular spreader was used to apply dazomet (Mylone), followed by raking or shallow cultivation plus harrowing to provide incorporation. Irrigation was then applied to seal the soil surface. Polyethylene covers, to hold in the gases and to prevent the entry of fresh weed seeds, were not adopted for use due to the additional materials and labor costs.

With an innovative machinist on staff, and experience gained through practical application, improvements in application equipment were made. An applicator which applied and incorporated the Mylone in one pass, leaving a prepared seedbed, was designed and fabricated. It was used for a number of years, but gave way to a new applicator when the product Basamid replaced Mylone in the Centre's program. The new applicator was designed along the lines of its predecessor, but incorporated a custom lathed roller instead of a chain link floor mat to distribute the dazomet product. This change was necessitated due to the much finer particle size of Basamid compared to Mylone.

Application Procedure

Current fumigation practices, at the Centre, involve the use of Basamid for both conifer and deciduous shrub seedbeds. The interval between fumigation and sowing varies depending on species: the shortest interval is four weeks for choke cherry (Prunus virginiana melanocarpa (A. Nels.) Sarg.), red elder (Sambucus racemosa L.) and white spruce (Picea glauca (Moench.) Voss.); four to six weeks for Siberian crabapple (Malus baccata (L.) Borkh.), red-osier dogwood (Cornus stolonifera Michx.), Ussurian pear (Pyrus ussuriensis Maxim.), Tatarian honeysuckle (Lonicera tatarica L.) and sea-buckthorn (Hippophae rhamnoides L.); and eight to ten months for Colorado spruce (Picea pungens Engelm.) and Scots pine (Pinus sylvestris L.).

The seedbeds are prepared and left reasonably level. Five days before Basamid application, the moisture content of the soil is brought to at least 50% of field capacity. The Basamid is applied at 350 kg of product per hectare and incorporated to a depth of ten centimetres by means of the shop built equipment previously mentioned. Following application and incorporation, the seedbeds are lightly packed using a roller. Light irrigation, approximately six millimetres, is then applied to complete the seal. For a three to five day period following treatment, sufficient moisture is provided to prevent the soil surface from drying out. After the active fumigation period, the soil can be tilled to aid in the dissipation of any remaining gases. Care must be taken to avoid tilling to a depth greater than that of original application.

In order to be certain that no toxic methyl isothiocyanate or formaldehyde gases are present in the soil at sowing time, a germination test should be performed using a susceptible species such as lettuce or cress (fig. 1).

Figure 1.-- Germination test to detect the presence of methyl isothiocyanate and formaldehyde gases.

CONCLUSION

Basamid, correctly applied, can provide an acceptable degree of weed control and more importantly, at the Shelterbelt Centre, control of soil-borne fungi such as pythium, fusarium, phytophtora and rhizoctonia. This is especially important in the conifer seedbeds where seedling losses can be significant.

Seedbed fumigation programs need to be reviewed periodically to determine if they are meeting the original objectives and if they are required.

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Methyl Bromide Fumigation of Containers Filled with Growing Media[1]

T. R. Garren, T. D. Landis, and S. J. Campbell[2]

Abstract.--Containers filled with peat-vermiculite growing media were fumigated with methyl bromide/chloropicrin (98%:2%), which was more effective than heat sterilization in controlling a soilborne disease. Because small volumes of growing media are isolated in spacially separate containers, considerably lower fumigant application rates were effective. Economic analysis proved methyl bromide fumigation to be cost effective because seedlings grown in treated containers were consistently larger.

INTRODUCTION

The greenhouse complex at the W.H. Horning Tree Seed Orchard was built in 1976 and is operated by the USDI-Bureau of Land Management to produce seedlings for tree improvement activities in northwestern Oregon. Annual production in the two shelterhouse-style greenhouses averages around 650M seedlings, depending on which container size is used. Reforestation seedlings are grown in Ray Leach pine cells^R [4 in^3 (65 cm^3)], whereas grafting root stock and seedlings for progeny tests are produced in Ray Leach super cells^R [10 in^3 (164 cm^3)].

During the 1982 growing season, several Northwest container nurseries began noticing a needle tip twisting and necrosis of Douglas-fir [Pseudotsuga menziesii (Mirb.)Franco] and other conifer seedlings. These initial symptoms were followed by stunting, chlorosis, and sometimes death of the affected seedlings. Because this species was most commonly affected, this disorder became known as Douglas-fir dieback (Husted 1988). Dieback symptoms are characteristic of many different types of root injury, including damage from fungal pathogens which could be transmitted in certain batches of growing media.

[1] Paper presented at the Intermountain Forest Nursery Association Meeting, Bismarck, North Dakota, August 14-18, 1989.

[2] Terry R. Garren is Supervisory Horticulturist, W.H. Horning Tree Seed Orchard, Colton, OR; Tom D. Landis is Western Nursery Specialist, and Sally J. Campbell is Plant Pathologist, USDA Forest Service, Portland, OR.

Container nursery managers observed that the symptomatic seedlings were often restricted to individual containers or blocks of containers (fig. 1). This "block effect" could be caused by a problem with reusable containers, or contaminated batches of growing media. Because the disease was more prevalent in previously-used containers, one hypothesis was that some sort of biological pathogen was being carried over between crops in the growing media that remained in the used containers. Another possibility was that batches of the peat-vermiculite growing medium could have become contaminated with a soilborne pathogen, and then distributed to specific groups of containers.

CONTAINER/GROWING MEDIA STERILIZATION TREATMENTS

Beginning in 1984, a series of operational experiments were conducted at the Horning greenhouse to see if the dieback problem could be cured with sterilization treatments of the containers or growing media. A battery of 21 different treatments was tried on a small scale during the 1984 growing season (fig. 2), but the only promising one involved heat sterilization of the growing medium in an autoclave. The soilborne pathogen hypothesis was further strengthened by the fact that healthy seedlings could be grown in batches of "bad soil" (media collected from containers with symptomatic seedlings) after it was autoclaved. Contaminated containers were also a possibility because a test between new and re-used containers revealed that 94% of the seedlings in the used containers exhibited dieback symptoms, compared to only 6% in the new containers.

Figure 1 - The "block effect", in which disease symptoms are restricted to seedlings in certain used containers, is thought to be related to soilborne pathogens which are transmitted on particles of growing media or root pieces that remain in the container between crops.

Based on these promising initial trials, two different methods of heat sterilization of the growing media were tested during the 1985 growing season. One batch of growing media was again autoclaved, and another treatment consisted the standard horticultural practice of steam sterilizing growing media, which was contracted to a local ornamental nursery. The steam sterilization contract specified that the growing media be held at a temperature of 200 °F (94 °C) for 30 minutes, instead of the normal heat pasteurization treatment which consists of temperatures of only 140 to 177 °F (60 to 82 °C) for the same time period. Following these heat treatments, the growing media was loaded into containers, and sown in the normal manner. A third growing media sterilization treatment with methyl bromide fumigation was added to further test the soilborne pathogen hypothesis. In this treatment, containers were filled with peat-vermiculite growing media and then fumigated with 98% methyl bromide/2% chloropicrin (MBC-2). At the end of the specified aeration period these filled containers were sown and placed in the greenhouse, and the seedlings were grown under normal nursery culture.

The 1985 sterilization trials revealed that, although the steam sterilization treatment gave poor results, both the autoclaved growing media and the MBC-2 fumigation greatly reduced or even

Figure 2 - Early operational trials with a variety of different container and growing media treatments showed that heat sterilization greatly reduced the number of symptomatic seedlings.

Table 1 - Container and growing media sterilization trials at the W.H. Horning greenhouse in 1985

TREATMENTS	NUMBER OF SEEDLINGS TOTAL	NUMBER OF SEEDLINGS SYMPTOMATIC	PER CENT OF TOTAL
STEAM STERILIZED GROWING MEDIA	154	49	31.8 %
AUTOCLAVED GROWING MEDIA	180	8	4.4 %
MBC-2 FUMIGATED GROWING MEDIA IN CONTAINERS[1]	194	0	0.0 %

[1] = Containers filled with growing media were fumigated with methyl bromide/ chloropicrin (98%:2%)

eliminated the number of symptomatic seedlings (table 1). Note that the steam sterilization and autoclave treatments involved only the growing media whereas the methyl bromide fumigation treated both the growing media and the containers. Although the Horning nursery personnel did not routinely sterilize their containers between crops, they did clean and sterilize small test groups of containers with Physan 20[R] or a 10% chlorox solution. These surface sterilants have not proven to be effective in killing fungal pathogens on containers, however, so infected growing media could still be transmitted on the containers to reinfect the new growing media (James and others 1988). This could possibly explain why the heat treatments were less effective than the chemical fumigation. The high amount of disease in the steam sterilization treatment could be attributed to difficulties in achieving uniform heat penetration of large volumes of growing media, whereas the autoclaved growing media was more effective because it was treated in smaller batches. Although differences in sample sizes and cultural treatments made statistical analysis difficult, it was concluded that the MBC-2 fumigation showed promise as an operational way to treat large numbers of filled containers. Even though the autoclave treatment was more effective than steam sterilization, it was considered to be impractical for large-scale nursery operations and was therefore eliminated from subsequent tests.

Building on the successes of the previous season, it was decided to implement the growing media and container sterilization treatments on an operational scale during the 1986 season, using thousands of filled containers instead of only a few hundred. The steam sterilization treatment was attempted again because it was felt that heat penetration problem could be corrected. A large batch of growing media was again steam sterilized before the containers were filled, and another group of filled containers was fumigated with MBC-2. A 50 lb (22.7 kg) tank of MBC-2 was used to treat a space of approximately 300 yd^3 (230 m^3), which converts to an application rate of 0.17 lb/yd^3 (0.10 kg/m^3). The fumigant was applied under a polyethylene tarp, and the pressurized liquid was introduced into an evaporation barrel to promote complete vaporization. After a standard aeration period, the containers were then seeded and grown under the normal cultural regime in the greenhouse.

Table 2 - Operational scale container and growing media sterilization treatments at the Horning greenhouse in 1986

TYPE OF TREATMENT	TOTAL SEEDLINGS	SYMPTOMATIC SEEDLINGS NUMBER	SYMPTOMATIC SEEDLINGS PERCENT
STEAM STERILIZED GROWING MEDIA	58,016	3,091	5.3 %
MBC-2 FUMIGATED GROWING MEDIA IN CONTAINERS[1]	12,544	2	0.0 %

[1] = Containers filled with growing media were fumigated with methyl bromide/ chloropicrin (98%:2%)

The results of the 1986 trials showed that chemical fumigation was again effective in treating the Douglas-fir dieback disease (table 2). The steam sterilization treatments were more effective than the previous year but still did not completely eliminate the disease symptoms. It is interesting to note that the MBC-2 fumigation treatment was again effective, even though the 0.17 lb/yd^3 (0.10 kg/m^3) rate was considerably lower than the 0.50 to 1.00 lb/yd^3 (0.30 to 0.60 kg/m^3) rate that is listed on the fumigant label for potting soil. Other sources also recommend higher application rates: Handreck and Black (1984) recommend a rate of 0.83 lb yd^3 (0.50 kg/m^3) for treating growing media, compared to Bunt (1988) who recommends 1.17 lb yd^3 (0.70 kg/m^3). This effectiveness at lower application rates may reflect the way that the MBC-2 is applied - the fumigant is able to penetrate the small volume of growing media in the individual containers much easier than a large pile of growing media.

Each year since 1986, the Horning greenhouse has used methyl bromide fumigation to sterilize their containers after they were filled with growing media, resulting in the elimination of Douglas-fir dieback. Although the actual cause of the Douglas-fir dieback syndrome was never identified at the Horning container nursery, the success of the methyl bromide fumigation suggests that it was caused by a biological pathogen, probably a root fungus. Research in British Columbia has shown that Pythium ultimum, a minor root pathogen, was associated with this disorder in Canadian container nurseries (Husted 1988).

CURRENT FUMIGATION PROCEDURES AND RESULTS

The following paragraphs describe the fumigation procedures currently in use at the W.H. Horning greenhouse.

The containers are filled with peat-vermiculite growing media in the normal manner, transported to the empty greenhouse, moistened to normal germination water content, and placed on the raised benches. Another layer of empty container racks is placed on top of the filled containers to provide an air space (fig. 3). The drain hole in the concrete floor is sealed to avoid leakage before the entire group of benches is covered with a 6-mil plastic tarp; this operation requires four people to make sure that the tarp does not hang up or tear on the corners. The tarp is then sealed around the bottom by wetting the concrete floor and placing bags of growing media around the edges. The temperature of the growing media is allowed to warm to around 60 °F (16 °C) through solarization, or the greenhouse is heated if the weather is cool and cloudy. It is important to moisten and warm the growing media in the containers to stimulate disease organisms, and make them more susceptible to the fumigant. Other container nursery managers have reported poor results when the containers were fumigated under dry, cool conditions (Jopson 1989; Schaefer 1989).

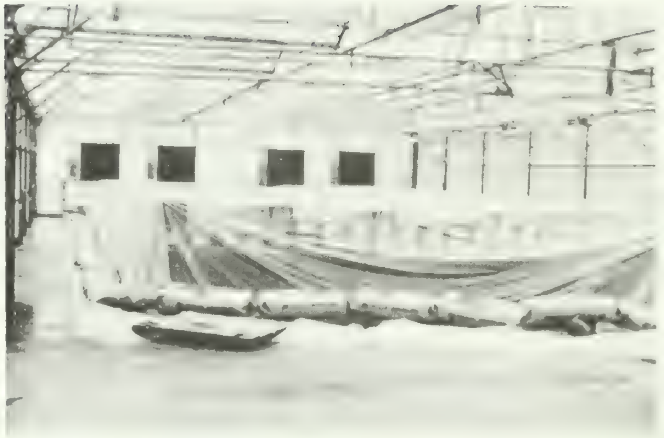

Figure 3 - Containers filled with moist growing media are fumigated with methyl bromide/chloropicrin (98%:2%) in a warm greenhouse by injecting the fumigant under a sealed polyethylene tarp.

The Horning greenhouse currently contracts with a private pesticide applicator to apply the methyl bromide after the filled containers are situated under the fumigation tarp. The contract applicator uses a "hot shot" application technique where the methyl bromide is injected over heated coils to produce more efficient vaporization; this technique allows them to use a very low MBC-2 application rate of 0.0035 lb/ft^3 (0.056 kg/m^3). Fumigation is normally done on a Friday to allow an exposure period of at least 3 days over the weekend; Handreck and Black (1984) recommend an fumigant exposure period of 2 to 4 days whereas Bunt (1988) specifies 4 to 5 days.

On the following Tuesday, the greenhouse cooling fans are used to exhaust any fumigant that may have escaped through the tarp. Next, the greenhouse is checked with a Draeger methyl bromide detector to make sure that it is safe to enter, because the concentration of methyl bromide in a work area should not to exceed 5 ppm. If it is safe to proceed, the fumigation tarp is removed from the benches, starting at the end near the exhaust fans. It is important to allow an adequate aeration period because some ornamental plants are sensitive to even small amounts of bromide. Methyl bromide can be difficult to remove from organic material, and so a 4 to 10 day period is usually recommended (Bunt 1988; Handreck and Black 1984). To make certain that it is safe to sow the seedling crop, lettuce seeds are sown in a couple of containers and the germinants are observed for a few days. If there are no problems, the filled containers are sown and placed in the greenhouse to begin the germination period.

Table 3 - Chemical fumigation produced larger Douglas-fir container seedlings for 2 consecutive growing seasons at the W.H. Horning greenhouse

GROWING SEASON	FUMIGATION[1] TREATMENT	FINAL SEEDLING SIZE HEIGHT (cm)	CALIPER (mm)
1988	UNFUMIGATED	25.4	2.88
	FUMIGATED WITH MBC-2	29.7	3.32
1989	UNFUMIGATED	17.4	2.33
	FUMIGATED WITH MBC-2	24.9	3.04

1 = Containers filled with growing media were fumigated with methyl bromide/ chloropicrin (98%:2%)

Increased seedling growth due to fumigation

Even though Douglas-fir dieback has not been a problem in recent years, the Horning greehouse still realizes a benefit of methyl bromide fumigation of the containers and growing media. In fact, all the different conifer species produced at the nursery have been grown in fumigated growing media with good results. A control treatment of unfumigated containers is left each year to check on fumigation effectiveness, and the growth of these seedlings is monitored during the growing season. In each of the last 2 years, the seedlings in the non-fumigated containers were initially chlorotic and stunted compared to the treated population. Although the seedlings eventually attained normal color and appearance, they remained measurably smaller throughout the growing season. When seedling height and caliper measurements between the two groups was compared, the seedlings in the non-fumigated containers were consistently smaller than the seedlings in the fumigated containers (table 3). Although the difference in seedling height may not be great enough to affect production, the smaller calipers could produce serious economic consequences. Many of the unfumigated seedlings would have to be culled using a 0.12 in. (3 mm) minimum caliper, which is common for coastal Douglas-fir seedlings in this size of container.

The economics of fumigation

Under the current system using a professional applicator, fumigation costs for a crop of 430,000 seedlings in 10 in^3 (164 cm^3) containers was:

Labor	
Nursery set-up labor	$ 700
Contract fumigation	1,700
Materials	
Fumigant	$ 400
Tarp	200
Total Cost	$3,000

Cost of fumigation per thousand (M) seedlings =

$3,000/430M = $6.98/M

A benefit:cost (B:C) ratio can be computed by comparing the $3,000 fumigation cost to the estimated increase in seedling yield. Average seedling losses to Douglas-fir dieback were estimated to be 11%, or 47.3 M of a 430 M crop. Using an average value for reforestation seedlings, the benefit of fumigation can be calculated:

47.3 M seedlings X $150/M seedlings = $7,095

For the more valuable tree improvement seedlings, the economic benefit is even greater:

47.3 M seedlings X $500/M seedlings = $23,650

A comparison of these benefits to the above costs produced favorable B:C ratios:

for reforestation seedlings

$7,095:$3,000 = 2.4:1

for tree improvement stock

$23,650:$3,000 = 7.9:1

CONCLUSIONS AND RECOMMENDATIONS

The W.H. Horning tree improvement greenhouse plans on continuing to fumigate their containers and growing media with methyl bromide as long as an economic benefit can be realized. The fumigation procedure outlined in this paper has proven to be safe and easy to monitor, and is not considered to be hazardous to nursery workers or the environment.

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A Review of Soil Solar Heating in Western Forest Nurseries[1]

Diane M. Hildebrand[2]

Abstract.--Eleven studies at 10 western forest nurseries are summarized. In 8 studies, solar heating resulted in significant reductions in populations of soil-borne plant pathogens. Five out of 8 studies reported significant reductions in weeds. Three out of 5 studies reported an increased growth reponse in a tree seedling crop. The best results are expected for a tree seedling crop sown soon after the solar heating treatment.

INTRODUCTION

Solar heating of soil, a technique for preplant pest control, was reported in 1976 by Katan and others working in Israel. Solar heating or solarization of soil is accomplished by sealing clear polyethylene sheeting over moist soil for several weeks during the summer. Soil temperature under the polyethylene is raised 8-15°C above that of uncovered soil by the prevention of evaporation and by the greenhouse effect (Mahrer 1979). Continuous or repeated sub-lethal temperatures under moist conditions over long periods of time, either kill pathogens and weeds directly or weaken them so they cannot survive (Pullman et al., 1981). Volatiles released from decomposing organic matter are trapped under the polyethylene and may also play a role in mortality of pests (Zakaria et al., 1980).

Because of successes in agricultural crops (Katan 1981), and in the search for alternatives to fumigation, the solar heating technique has been evaluated at forest tree nurseries across the West. This paper attempts to summarize the results of the various experiments with solar heating in western nurseries. The author apologizes for any studies overlooked or misinterpreted.

SUMMARY OF RESULTS

Six studies reported only the effects of solar heating on pest populations (Table 1). In Placerville, California (38°40' latitude), populations of Fusarium were significantly reduced, while those of Macrophomina were not, after 5 weeks of solar heating. (McCain et al., 1982). In Paradise, California (39°40' latitude), weeds were reduced while Fusarium populations were not after 3 weeks of solar heating[3]. After 8 weeks of solar heating nursery soil at Fort Collins, Colorado (40°30' latitude), populations of Fusarium and Pythium remained significantly reduced through the following spring, while weeds returned to pretreatment levels by the following spring (Hildebrand 1987). In one study in Halsey, Nebraska (41°30' latitude), populations of Fusarium, weeds, and plant-parasitic nematodes were significantly reduced after 6 weeks of solar heating, but the fall-sown crop of eastern redcedar was lost due to an untimely frost (Hildebrand and Dinkel, 1988). In Washington, Oklahoma (35° latitude), weeds (except for yellow nutsedge) and populations of Pythium and Fusarium were significantly reduced while those of Macrophomina were not, after 8 weeks of solar heating (Miles 1988). In Boscobel, Wisconsin (43°10' latitude), pathogen populations were not reduced after 8.5 weeks of solar heating (Zarnstorff and Berbee, 1983).

Five studies reported data on treatment effects on a tree seedling crop (Table 1). In Davis, California (38°30' latitude), Agrobacterium populations were significantly reduced, and walnut and peach showed increased height and weight (Stapleton and DeVay, 1982). In Ames, Iowa (42° latitude), after 4 weeks of solar heating, weeds were reduced and pine seedlings (sown after winter fallow) showed inconsistent growth effects: half of the red pine attained greater seedling height and half of the white pine attained greater seedling weight (Croghan et al., 1984). In another study in Halsey, Nebraska (41°30' latitude), populations of Pythium and weeds returned to pretreatment levels the spring following 8 weeks of solar heating. In this Nebraska study, the lodgepole pine seedlings sown the following spring showed no benefit, but

[1]Paper presented at the Intermountain Forest Nursery Assoc. Meeting, Bismarck, North Dakota, August 11-14, 1989.

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Table 1.--Summary of results of 11 solar heating studies in western forest nurseries.

LOCATION	PATHOGENS REDUCED	WEEDS REDUCED	TREE SEEDLING GROWTH EFFECTS
Davis, CA	+	--	+
Paradise, CA	no	+	--
Placerville, CA	+	--	--
Fort Collins, CO	+	no	--
Ames, IA	no	+	+
Halsey, NE	+	no	no
Halsey, NE	+	+	--
Washington, OK	+	+	--
Bend, OR	+	no	no
Central Pt., OR	+	+	+
Boscobel, WI	no	--	--

+ = Positive effect; no = No effect;
-- = Not reported.

but the winter cover crop of oats sown after solar heating showed an increased growth response (Hildebrand 1987). At Bend, Oregon, (44° latitude), *Fusarium* populations were significantly reduced, while weed populations and growth of ponderosa pine seedlings (sown after winter fallow) were not affected by 4 weeks of solar heating (Cooley 1983). At Central Point, Oregon, (42°23' latitude), populations of weeds and *Fusarium*, but not of *Pythium*, were reduced significantly, and dry weight of Douglas-fir seedlings (sown after winter fallow) increased significantly after 6.5 weeks of solar heating (Cooley 1985).

Five of the studies also compared solar heating with chemical treatments (Table 2). Where MC-33 (67% methyl bromide and 33% chloropicrin) was used, fumigation consistently resulted in better seedling survival, but not always better weed control or seedling growth.

Temperature data varied between studies. Highest temperatures reported under the polyethylene were as follows: at Placerville, California, 56.2°C at 10 cm depth and 39.6°C at 20 cm (McCain et al., 1982); in Ames, Iowa, 51°C at 5 cm and 41.5°C at 15 cm (Croghan et al., 1984); at Bend, Oregon, 50+°C at 5 cm (Cooley 1983); in Boscobel, Wisconsin, 49°C at 5 cm and 41°C at 15 cm (Zarnstorff 1983); in Halsey, Nebraska, 46+°C (offscale on

Table 2.--Summary of comparisons between solar heating and chemical treatments for effects on pest populations and tree seedling growth.

Parameter	Bend, Oregon (1)	Central Point, Oregon (2)	Halsey, Nebraska (4)	Halsey, Nebraska (6)	Ames, Iowa (3)	
PEST POPULATIONS						
Pythium	--	M > S = C	M > S = C	--	--	
Fusarium	M > S > C	M > S > C	--	M > S ≥ PB > C ≥ WB	V > S = C	
Pathogenic Nematodes	--	--	--	M = PB = WB > S >> C	--	
Weeds	M > S > C	M = S > C	M > S > C	S ≥ M ≥ WB ≥ PB ≥ C	S > C	
SEEDLING DATA						
Survival	M > S = C	M > S = C	M > S = C	--	V = S = C	
Species	Ponderosa	Douglas-fir	Lodgepole	--	White pine	Red pine
Height	--	M = S = C	--	--	1/2: S ≥ V ≥ C 1/2: C = S = V	V = S > C V = S = C
Weight	--	M = S = C	--	--	1/2: V = S = C 1/2: S > C > V	V = S = C V = S = C
Root Length	--	M = S = C	--	--	--	
Caliper	--	M = S = C	--	--	--	

M = MC-33; V = Vorlex; PB = Basamid sealed with polyethylene; WB = Basamid sealed with water; S = Solar heating; C = Check; > = Better than; ≥ = Better than or equal to; -- = Not reported or populations too low to show a treatment effect.

thermograph) for 6 hours at 8 cm and 44°C for 4 hours at 15 cm (Hildebrand 1987); at Central Point, Oregon 43°C at 5 cm (Cooley 1985); and in Fort Collins, Colorado, 41+°C (offscale of thermograph) for 10 hours at 8 cm and 41+°C for 8 hours at 15 cm (Hildebrand 1987).

In 8 of the 11 studies reviewed, solar heating resulted in significant reductions in pathogen populations. Of 8 studies reporting effects on weeds, 5 showed significant reductions in weeds. Of 5 studies reporting seedling growth effects, 3 studies showed an increased growth response in a tree seedling crop; and none showed increased seedling survival. In conifers sown the spring following solar heating, the increased growth response was inconsistent or non-existent. The best growth response was in a crop sown in the fall after solar heating, as reported for the walnut and peach in California (Stapleton and DeVay, 1982) or in the winter cover crop of oats in Nebraska (Hildebrand 1987).

The solar heating technique works well with only a few weeks of polyethylene cover in hot climates like southern California and Israel for crops sown immediately after solar heating. Here in the western United States, even 8 weeks of polyethylene cover have not proven reliable for controlling pests and increasing growth and survival of conifer crops sown the spring after treatment. The best results would be attained for a fall-sown crop. The effects of solar heating on eastern redcedar sown in late August, 1989, are currently being tested in Nebraska.

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Soil Fumigation in Southern United States Forest Tree Nurseries[1]

C. E. Cordell[2]

Abstract.--Soils in bareroot forest tree nurseries in the Southern United States have been safely and efficiently fumigated for three decades. The primary target organisms are the soilborne pathogenic fungi that cause root rot and damping-off on both conifer and hardwood seedlings. A formulation of 67 percent methyl bromide and 33 percent chloropicrin has consistently provided the most effective control of these diseases. Methyl bromide is presently used in over 90 percent of the southern nurseries. Alternative soil treatments are urgently needed. Guidelines and precautions on fumigants, application methods, benefits and costs, and registration and safety are presented. Factors affecting soil fumigation results are emphasized.

Additional keywords: Soil fumigants, nursery treatments, guidelines, precautions, benefits, costs, registration, and safety.

Soils in southern forest tree nurseries have been routinely fumigated for the past three decades. In more recent years, these chemical soil treatments have been utilized in nurseries in the Northeastern, Central, North-Central and Western United States. Mixtures of methyl bromide and chloropicrin, dicloropropenes, ethylene bromide, vapam, vorlex, and dazomet have been utilized with varying degrees of success. However, the methyl bromide-chloropicrin formulations have consistently provided the most effective and efficient results (Cordell, 1983; Seymour and Cordell, 1979; Cordell and Kelley, 1985). The vast majority (90+ percent) of southern nurseries presently utilize methyl bromide (Boyer and South, 1984). Approximately 2,400 acres are treated annually at an estimated cost of $1.9 million. The methyl bromide- 67%; chloropicrin - 33% (MC-33) formulation is routinely utilized where difficult-to-control root disease organisms are known to occur and highly susceptible seedling hosts will be grown. Alternative soil treatments are urgently needed and several chemical and nonchemical treatments are being tested as suitable alternatives to methyl bromide.

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APPLICATION METHODS

The methyl bromide-chloropicrin (MBC) soil fumigants are most commonly applied beneath the soil with a chisel injector (Cordell and Kelley, 1985). This tractor-drawn machine is equipped with chisels not over 30 cm. (12 inches) apart and adjusted to inject the fumigant at the optimum depth of 20-25 cm. (8 to 10 inches). More recently, machines have been developed that permit fumigant injections at soil depths of 30 cm. (12 inches) or more where particularly damaging disease organisms threaten the production of deep-rooted hardwood species, such as yellow-poplar (*Liriodendron tulipifera* L.), black walnut (*Juglans nigra* L.), and sweetgum (*Liquidambar styraciflua* L.), and where fine-textured soils reduce fumigant penetration (Cordell, 1983).

MBC fumigants can be applied to the soil surface (Cordell, 1983). For soil surface applications, the fumigant is released from pressurized containers into evaporation pans located under polyethylene covers. The polyethylene covers are raised above the soil surface to permit horizontal gas movement across the treated area. This method is most suitable for fumigating small seedbeds, transplant beds, and other localized areas. Advantages of this method include the relative low cost of the equipment and simplicity of application. A primary disadvantage is the time required to treat large areas. Several times more nursery acreage can be fumigated per day with the mechanized soil-injection machines than with the labor-intensive surface applications.

MBC mixtures also are used to fumigate bulk soil mixes and mulch materials such as grain straw, pine needles, and bark chips (Cordell, 1983). The soil mixes are used for container-grown seedlings, while the various types of mulches are used on bareroot nursery seedbeds.

Fumigant dosage rates are based on the amount of active chemical ingredient needed per hectare or acre. Rates vary by chemical, target organism, application method, soil type and environmental conditions. To be effective, a fumigant must remain in contact with the target organism for sufficient time and in sufficient concentration to kill. Therefore, the fumigant dosage must take into account the chemical concentration needed per unit of soil volume and the exposure period. For bulk soil and mulch materials, MBC (MC-33 or MC-2) fumigant application rates are 0.56 kg/m^3 (1.0 lb./yd^3)(Cordell, 1983).

The fumigated soil or mulch material must be adequately covered or sealed to promote maximum fumigation effectiveness. The most effective cover is polyethylene with sufficient strength and thickness to minimize fumigant escape. The fumigation and tarping can be done on entire fields or on alternate strips (Fig. 1). Fumigation of entire fields minimizes the opportunity for contamination from adjacent nonfumigated strips. In addition, the fumigation time requirement for continuous tarping is considerably shorter than for strips. Thus, an earlier planting date following spring fumigation is possible and the probability of unfavorable weather interference is reduced. A major disadvantage of continuous tarping is that the large covers that are required are much more subject to wind damage than the smaller covers used in strip fumigation (Cordell and Kelley, 1985).

Soil can be fumigated either in the spring or the fall. In the fall, soil temperature and moisture conditions in the Southern United States are near optimum for fumigation, and treatment then fits better into nursery work schedules. Spring fumigation has the major advantage of being closer to seed sowing time. As a result, the probability of recontamination of treated seedbeds is reduced. Spring soil fumigation is also highly recommended when the seedbeds will be artificially inoculated with ectomycorrhizal fungi (Marx and others, 1984).

FUMIGATION GUIDELINES

Soil fumigants are broad spectrum biocides - they can kill most living things - and they are relatively expensive to purchase and apply. Consequently, it is highly desirable to apply a soil fumigant under conditions and using equipment and procedures that maximize safety and effectiveness (Table 1). Safety and effectiveness have been considered in formulating guidelines for soil fumigation in the Southern United States (Seymour and Cordell, 1979; Cordell, 1983; Cordell and Kelley, 1985).

Figure 1.--Solid tarping (above) and strip tarping (below) are two alternatives when fumigating with methyl bromide.

BENEFITS AND COSTS

Specific fumigants vary in their effectiveness against specific soil organisms. MC-33 has repeatedly and consistently provided the most effective control of soilborne pathogenic fungi such as Machrophomina phaseolina and Fusarium spp., the causes of charcoal and black root rot; Phytophthora spp. Phythium spp., the causes of damping-off and root rot diseases; and Cylindrocladium spp., the causes of cylindrocladium root rot (Cordell, 1983; Cordell and Kelley, 1985; Seymour and Cordell, 1979; Smith and Bega, 1966; Johnson and Bigelow, 1975). These organisms are the primary targets of soil fumigation in southern nurseries. MBC formulations have also provided effective control of nematodes, soil insects, certain weed seeds, and other soilborne pathogenic fungi (Hansbrough

Table 1. Suggested guidelines and precautions for effective soil fumigation.[1]

Soil fumigation factors	Guidelines and precautions
Soil preparation	Work into fine, loose, friable condition to minimum depth of 20 to 25 centimeters. Soil should be as free of clods as possible.
Organic matter	Do not use nondecayed organic matter. Organic matter can render fumigant ineffective and harbor fungi and nematodes. Cut or chop green organic matter into the soil a minimum of 3 to 4 weeks prior to fumigation.
Soil moisture	Soil moisture neither too high nor too low. Coarse-textured sandy soils - 75 percent field capacity2/ Fine-textured clay soils - 25 to 50 percent field capacity
Soil temperature	Soil temperature above 10C at 15-centimeter depth. Air and soil temperatures not usually correlated.
Soil fumigants and target pests	Mixtures of 98% methyl bromide/2% chloropicrin fumigant; broad spectrum for nematodes, weeds, insects, and most soilborne fungi. Mixtures of 67% methyl bromide/33% chloropicrin fumigant; particularly effective against soilborne fungi with tough resistant stages.
Calibrating and monitoring soil fumigation equipment.	Fumigant dosage = concentration X time. Dosage determined by injector nozzle size, fumigant pressure, and tractor speed. Fumigant injected at minimum 20-centimeter soil depth. Deeper soil injections for deeper-rooted species. Maintain constant pressure, tractor speed, and fumigant flow through all nozzles for uniform, effective coverage.
Soil tarping	Apply clear polyethylene tarp with adequate strength and thickness immediately after fumigation for maximum effectiveness. Alternate strips require longer fumigation and time intervals and afford opportunity for contamination from adjacent nonfumigated soil strips. Solid tarping requires shorter fumigation time interval and minimizes opportunity for soil contamination. Repair and seal any holes and open glue joints immediately.
Fumigation exposure period	Consult fumigant label for recommendations. Minimum of 48 hours at soil temperature above 15C at 15-centimeter depth. At lower temperatures and during wet weather (following fumigation) double the exposure period.
Fumigation aeration period	Consult fumigant label for recommendations Minimum of 48-72 hours; varies with fumigant, soil, temperature, moisture, and crop to be planted. Double aeration period in wet weather or at temperatures below 15C.
Extended aeration for seedbeds receiving artificial inoculations of ectomycorrhizal fungi	Aerate soil at least 3 weeks following mixture of 67% methyl bromide/33% chloropicrin fumigation. This strong fumigant has extended residual toxicity to all soil fungi, including those which form mycorrhizae.
Contamination of fumigated soils	Avoid possible contamination by movement of soil, plants, mulches, etc., into fumigated areas. Clean, by steam or equivalent, all equipment: plows, bed shapers, tractor tires, etc. Avoid transplanting from nonfumigated soils.
Fumigation of mulch materials	Prefumigate mulch materials such as pine needles, straw, and bark with mixture of 67% methyl bromide/33% chloropicrin or mixture of 98% methyl bromide/33% chloropicrin formulations at a dosage rate of 0.59 kg/m^3. Tightly compacted or baled materials should be a maximum of 45 centimeters deep. Loose pine needles, straw, etc., may be 0.8 to 1.2 meters deep. Fumigation procedures and precautions (tarping, temperature, moisture, exposure, aeration periods, etc.) are same as for soil fumigation.
Soil nutrient alterations	Level of soluble salts and ammonia nitrogen may be increased due to decreased populations of nitrifying bacteria. Do not use ammonia fertilizers on plants requiring nitrates or those sensitive to ammonia. Apply only nitrate fertilizers until seedlings are established and soil temperature is above 20C. Base your fertilizer applications on soil tests made after fumigation.
Water requirements	Water requirements per unit of plant production are generally less. Water requirements per acre are increased due to generally larger plants and increased production.
Cover crops	Green manure cover crop plants such as corn, peas, sorghum, and soybeans are highly susceptible hosts for the charcoal and black root rot fungi. Grain crops such as millet, sudan, and rye are considered nonhosts.
Safety	The methyl bromide/chloropicrin formulations are highly toxic to animals (including humans) and plants. Handle fumigants with care and only by certified competent personnel.
	ALWAYS READ FUMIGANT LABEL PRIOR TO USE AND FOLLOW ALL DIRECTIONS AND PRECAUTIONS CLOSELY.

1/ Seymour, C. P. and Cordell, C. E. 1979. Control of charcoal root rot with methyl bromide in forest nurseries. Southern Journal of Applied Forestry. Vol. 3:3. p. 104-108.

2/ Water-holding capacity of the soil against the force of gravity.

and Hollis, 1957; Hodges, 1960; Clifford, 1951; Hill, 1955; Foster, 1961; Thomason, 1959). In the past, annual weeds were the primary target pests in southern nurseries. However, the recent development of equally effective and less expensive herbicides has resulted in major modifications in nursery pest control objectives (South and Gjerstad, 1980). Soil fumigation with MBC formulations has also consistently improved seedling quality and reduced cull factors in nurseries (Clifford, 1963; Hodges, 1960; Rowan, 1971; Seymour and Cordell, 1979). Soil fumigation with MBC-2 in a Louisiana experimental nursery almost doubled the production of plantable seedlings and resulted in corresponding significant increases in seedling quality (Hansbrough and Hollis, 1957). Variable effects have been observed on nontarget organisms and other related soil factors (Foster, 1961, Hacskaylo and Palmer, 1957; Kelley and Rodriguez-Kabana, 1979). For example, the beneficial ectomycorrhizal fungi are usually only temporarily decreased, even after spring soil fumigation (Marx and others, 1984).

The present cost of soil fumigation in southern nurseries ranges between \$2,000 and \$2,500 per hectare (\$800 and \$1,000 per acre). The cost varies with the fumigant type and formulation, dosage rate, soil cover type and thickness, acreage fumigated, and whether the fumigant is commercially or privately applied. Based on the present average southern pine seedling production of 1.85 million seedlings per hectare (750,000 seedlings per acre), this cost ranges between \$1.07 and \$1.33 per thousand seedlings. Assuming an average pine seedling value of \$30.00 per thousand, the present cost of fumigation is less than 5 percent of the seedling value.

REGISTRATION AND SAFETY

The chemical fumigants mentioned previously are specifically registered by the U.S. Environmental Protection Agency (EPA) as preplanting soil fumigants for the control of a variety of soil fungi, nematodes, insects, broadleaf weeds, and grasses in forest tree nurseries. Although most of these fumigants are highly toxic to humans, animals, and plants, they can be as safely employed as any other chemical pesticide by considering their potential toxicity and taking appropriate precautions.

The pesticide label for the specific fumigant type and formulation to be used should be read and understood prior to use. All handling and application directions and safety precautions should be closely followed. The fumigant must be applied only by nursery personnel who are certified by the respective State pesticide regulatory agency. Recommended protective equipment should always be utilized as directed.

Remember, fumigants such as MBC formulations are listed as restricted use pesticides by EPA. That designation means that use of them is restricted to the conditions, concentrations, and applications specified by EPA and listed on the pesticide label.

DISCUSSION AND CONCLUSIONS

When the cost of soil fumigation is compared with the benefits from its use, it becomes apparent that this practice is economically justified in southern nurseries. This is particularly apparent where damaging soilborne root diseases and susceptible seedling host species occur. Charcoal root rot caused the loss of approximately 16.5 million saleable seedlings of five species of southern pines in a Florida nursery in 1976 (Seymour and Cordell, 1979). Benefit/cost analyses in an Alabama State Nursery showed that soil fumigation with MBC was economically justified when seedling root disease caused a loss of 1.8 percent or more of the saleable pine seedlings (Kucera, 1981). Also, these benefits have been extended to the outplanting site, where increased survival and more rapid early growth have been observed on seedlings from fumigated nursery beds (Foster, 1961).

Effective, efficient, and safe soil fumigation has been repeatedly obtained with the techniques and procedures previously described. MC-33 has been most effective for controlling soilborne, fungus-caused diseases such as root rots which are the most damaging pests in southern nurseries. However, alternative soil treatments are urgently needed for the intensively utilized MBC fumigants. Withdrawl of these formulations from the current EPA pesticide registration list for nursery fumigation would severely limit the quantity and quality of seedling production in southern nurseries.

An alternative chemical fumigant, metam sodium (vapam, 33% a.i.) has possible applications in U.S. nurseries. It has proven effective in Israel for control of soil pathogenic fungi (Ben-Yephet and others, 1988; Widin and Kennedy, 1983). Application methods include broadcasting vapam granules and mixing them into the soil, drenching the soil with a liquid formulation, and application through the nursery irrigation system.

Recently, a soil solarization technique has been developed and perfected in Israel to control soil pathogens (Katan and others 1976). This technique has been independently tested with variable success in several countries (Horiuchi, 1984; Katan and others, 1976; Stapleton and DeVay, 1986). Soil solarization is a rather simple technique that involves covering wet soil with clear plastic covers to create a greenhouse effect with the natural sunlight for a period of 4 to 6 weeks during the hottest months of the year. This procedure raises the soil temperature high enough (40 to 50 C) to significantly reduce the populations of undesirable soil organisms. Two primary factors affecting the success of the technique are high soil temperatures and adequate

moisture (Horiuchi, 1984). Solarization has failed to control certain soil pathogenic fungi, such as the charcoal or black root rot fungi which have relatively high temperature tolerances (≥ 50C) (Mihail and Alcorn, 1984; Stapleton and DeVay, 1986; English, Mitchell, and Barnard, 1982). Effective results have been obtained with a combination of solarization and chemicals where the efficacy of the chemical was increased at the higher soil temperatures (Ben-Yephet and others, 1988).

MC-33 soil fumigation or its equivalent is presently considered mandatory in southern nurseries where susceptible seedling hosts and root rot disease fungi occur in combination. The previously described potential pest threats without fumigation, along with the consistent benefits derived from its use, clearly demonstrate the biological and economical advantages of this practice. It helps to ensure the sustained production of high-quality seedlings with improved survival and growth capabilites for field plantings. Consistently effective results can be obtained by considering the target organisms and the nursery environment when selecting and applying a soil fumigant.

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Use of VA Mycorrhizal Innoculum to Improve Growth of Forest Tree Seedlings in Fumigated Soil[1]

Tim Wood, Libby Nance, Steve Jedrzejek, and Greg Johnson[2]

Inoculation of fumigated nursery soils with VA mycorrhizal fungi improved the growth and quality of Russian olive, Sierra redwood, incense cedar and western red cedar seedlings in two West Coast forest nurseries. Experiments were used to identify superior fungal strains for use on acid, low-phosphorus soils. Commercial VA mycorrhizal inoculants, based on these strains, are under development.

INTRODUCTION

Forest nursery soils are often fumigated with methyl bromide to promote production of disease-free seedlings. Methyl bromide is a general biocide, and in addition to killing soil-borne pathogens, it eliminates beneficial vesicular-arbuscular (VA) mycorrhizal fungi. VA mycorrhizal fungi form symbiotic associations with the roots of some forest tree species (most notably redwoods, cedars, junipers and many broadleaf species), and they aid those plants in uptake of nutrients. Elimination of these fungi via fumigation can lead to plant nutrient deficiencies, stunting and crop loss, particularly on low-phosphorus and/or phosphorus-fixing soils.

The studies reported here compare the efficacies of several VA mycorrhizal fungi in promoting the growth and quality of tree seedlings on fumigated soils in two West Coast forest nurseries.

METHODS AND MATERIALS

In the spring of 1988, field trials were established at the California Department of Forestry nursery at Magalia, CA, and at the D.L. Phipps State Forest Nursery at Elkton, OR.[3] The soils at Magalia were acid clay loams (pH 5.0-5.3). They showed significant phosphorus (P) fixation capacities, and contained low levels of water extractable P (0.2 µg P/g soil as measured in 1:10 soil:water extracts). Elkton soils were acid sandy loams (pH 4.7-4.8). They showed moderate P fixation capacities, and contained variable levels of water soluble P (1.2-5.0 µg P/g soil).

Cultural practices and experimental procedures used at the two nurseries were similar. Seven months prior to the field tests, soils were fumigated with methyl bromide - chloropicrin mixtures at 393 kg/ha. In March, 1988, prior to seeding, ground was power harrowed and beds (1.2 m wide) were shaped. Beds were then measured off to delineate meter-long inoculuation plots separated by 3-4 m non-inoculated buffers. Plots were laid out in complete randomized blocks with 4-5 repetitions per tree species x inoculation treatment.

Three strains of VA mycorrhizal fungi were chosen for the field tests at each nursery. Selections were based on superior performance in greenhouse trials involving acid soils. Inoculants consisted of colonized root fragments and fungal spores in a moist sand carrier. Each treatment plot was inoculated by incorporating 750 g of this material uniformly into the upper 15-20 cm of the soil. Non-inoculated control plots received 750 g of sand carrier only.

Following inoculation, beds were seeded using an eight-row seed drill. Russian olive (Elaeagnus angustifolia), Sierra redwood (Sequoia gigantea) and incense cedar (Calocedrus decurrens) were sown at Magalia. Sierra redwood, incense cedar and western red cedar (Thuja plicata) were sown at the Elkton nursery. Seedlings were grown using cultural practices standard to the two nurseries.

In April, 1989, the seedlings were harvested. Thirty plants from each plot were selected at random and were measured to determine height and caliper. In addition, 50 seedlings of each species were subjected to dimension analysis. Equations for estimating seedling dry weight and seedling root volume from caliper measurements were developed. For all species, regression equations took the form:

dry weight or root volume = m $(\text{caliper}^{2.5})$

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3. The authors would like to acknowledge the assistance of Bill Krelle and David Pilz who oversaw site preparation and maintenance of the trials at the CDF and D.L Phipps nurseries respectively.

In all instances, correlation coefficients for these regression equations ranged from 0.80 to 0.98. Seedling dry weights and root volumes were then estimated for the 30 seedlings in each field plot using caliper data. Finally, for each tree species x inoculation treatment, means and standard deviations for seedling height, caliper, estimated dry weight and estimated root volume were calculated. Analyses of variance were run, and signifcant differences between inoculation treatments were determined using Tukey's *w* procedure, $p \leq 0.05$.

RESULTS

Inoculation of fumigated nursery soils with VA mycorrhizal fungi generally improved the growth of the tree seedlings tested. Importantly, there were significant differences in efficacy between fungal strains. Sample results are given in Tables 1 and 2.

Table 1: 1988 VAMF Strain selection trial with one-year Russin olive (E. angustifolia) seedlings. California Department of Forestry Nursery Magalia, Ca.

VAMF Strain No.	Seedling Height (cm)	Seedling Caliper (mm)
25	26.9 ± 6.7^{b}	2.8 ± 0.6^{b}
60	22.1 ± 5.0^{b}	2.6 ± 0.3^{b}
31	9.6 ± 4.8^{a}	1.4 ± 0.4^{a}
Control	9.0 ± 3.8^{a}	1.4 ± 0.5^{a}
VAMF Strain No.	**Est. Seedling Dry weight (g)**	**Est. Seedling Root volume (ml)**
25	3.0 ± 1.3^{b}	5.2 ± 2.3^{b}
60	2.1 ± 0.5^{ab}	3.6 ± 0.9^{ab}
31	0.6 ± 0.4^{a}	1.0 ± 0.7^{a}
Control	0.8 ± 0.9^{a}	1.3 ± 1.5^{a}

Mean separation within colums by Tukey's *W*-procedure ($p \leq 0.05$)

At the Magalia nursery, Strain 25, a Glomus intraradices isolate adapted to acid soils, proved to be superior. When applied to beds of Russian olive, it increased seedlings height growth three-fold, caliper growth two-fold, and estimated seedling dry weight and root volume more than three-fold (Table 1). Strain 60 also improved the growth of Russian olive. Seedlings inoculated with Strain 31 showed no improvements over non-inoculated controls. Similar responses to inoculation were observed with Sierra redwood and incense cedar at the Magalia nursery, and in each case, Isolate 25 was the superior inoculant.

VA mycorrhiza inoculation also improved seedling growth at the Elkton nursery, and again Isolate 25 was superior. In comparison to non-inoculated controls, incense cedar seedlings showed two-fold increases in height and caliper, and five-fold increases in estimated seedling dry weight and root volume when inoculated with this strain (Table 2). Isolates 31 and 54 also improved seedlings growth, but increases were only about half as large as those found with Strain 25. Similar responses to inoculation were found with Sierra redwood and with western red cedar at Elkton, and again, in each case, Isolate 25 produced superior seedling growth.

Table 2: 1988 VAMF Strain selection trial with one-year incense cedar (C. decurrens) seedlings. D.L Phipps State Forest Nursery Elkton, Or.

VAMF Strain No.	Seedling Height (cm)	Seedling Caliper (mm)
25	31.7 ± 0.9^{c}	4.5 ± 0.6^{c}
54	24.5 ± 2.5^{b}	3.4 ± 0.7^{b}
31	21.2 ± 4.0^{b}	3.2 ± 1.0^{b}
Control	14.6 ± 3.8^{a}	2.2 ± 0.5^{a}
VAMF Strain No.	**Est. Seedling Dry weight (g)**	**Est. Seedling Root volume (ml)**
25	3.9 ± 1.5^{c}	2.0 ± 0.7^{c}
54	2.2 ± 1.1^{b}	1.1 ± 0.6^{b}
31	2.0 ± 1.6^{ab}	1.0 ± 0.8^{ab}
Control	0.7 ± 0.3^{a}	0.4 ± 0.2^{a}

Mean separation within colums by Tukey's *W*-procedure ($p \leq 0.05$)

DISCUSSION AND CONCLUSIONS

Inoculation of fumigated nursery soils with VA mycorrhizal fungi significantly improved the growth of Russian olive, Sierra redwood, incense cedar and western red cedar in two West Coast forest nurseries. Several strains of fungi were compared, and in both nurseries and with all tree species tested, one isolate, a Glomus intraradices strain, was most efficaceous. This fungus gave two-to-five-fold increases in seedling height, caliper, dry weight and root volume over non-inoculated control plants. Of the other isolates tested, some gave intermediate responses, and some yielded no improvements in seedling growth.

These results underscore the importance of strain selection in the development and use of mycorrhizal inoculants. The VA mycorrhizal fungi tested in this study showed little if any host specificity in the sense that a single isolate gave the superior growth responses across all three species tested. However, in testing more than 100 strains in greenhouse experiments, we have found these fungi to be specific to soil type, and in particular to soil pH. Some strains work well in neutral-to-basic soils (pH 6.5 and above), while others, like Strain 25 in this study, give superior plant growth on acid soils below pH 5.5. In all cases, inoculation with VA mycorrhizal fungi is most efficaceous when soils have low levels of available phosphorus and/or significant phosphorus fixation capacities. Commercial VA mycorrhizal inoculants comprising the superior fungi indentified in these studies, are now being developed for use in forest nurseries.

Variable Seed Dormancy in Rocky Mountain Juniper[1]

W. J. Rietveld[2]

Abstract.-- Rocky Mountain juniper is difficult to grow in the nursery due to variable seed dormancy that spreads germination over time. In two experiments, six seed sources, five seed treatments, and 15 stratification treatments were tested. Although there were some seed source and stratification treatment differences, none of the treatments effectively enhanced germination amount or timing enough to be useful in nursery culture.

INTRODUCTION

Rocky Mountain juniper (Juniperus scopulorum Sarg.) (RMJ) is widely planted for windbreaks and wildlife habitat in the Great Plains. The popularity and importance of this species resides in its cold hardiness, tolerance to drought, and relative freedom from insect and disease problems. In a windbreak, junipers provide a dense barrier throughout the year, resulting in excellent wind protection and snow control.

Despite its popularity, RMJ is difficult to grow in the nursery. Variable seed dormancy, and consequent low and variable germination are the underlying causes of these problems. The degree of seed dormancy varies by seed crop, seed source, seed age, and probably among and within individual trees (Van Haverbeke and Comer 1985, Young et al. 1988). Berries persist on the tree for 2-3 years, so a single collection could contain berries of varying age, including immature berries (Johnson and Alexander 1974). While seed dormancy is an ecologically important device to optimize the distribution of the species in time and space, it is an obstacle in nursery culture where prompt, uniform, and complete germination is required in order to grow high quality planting stock.

Juniper seed has both seed coat and chemical dormancy (Gerbracht 1937, Pack 1921). The seeds have a thick, semi-permeable seed coat that must be conditioned to imbibe water. Efforts to increase the permeability of the seed coat of juniper seeds have included depulping (Afanasiev and Cress 1942); soaking seeds in sodium-lye (Webster and Ratliffe 1942), alcohol or boiling water (Chadwick 1946), concentrated sulfuric acid (Barton 1951), citric acid (Cotruto 1963, Van Haverbeke and Comer 1985), and hydrogen peroxide (Trappe 1961, Riffle and Springfield 1968); and freezing seeds in ice (Jelley 1937).

Although the usual method to overcome embryo dormancy of juniper seeds is classical cool/moist stratification for conifer seeds, stratification should not be restricted to cool temperatures. Van Haverbeke and Comer (1985) found that germination of eastern redcedar (Juniperus virginiana L.) seeds is enhanced by a combination of warm/moist stratification (75° F. for 6 weeks) followed by cool/moist stratification (41° F for 10 weeks).

The recommended stratification treatment for RMJ is warm/moist (68° F night/86° F day) for 45-90 days, followed by cool/moist (41° F) for 30-120 days to induce germination (Johnson and Alexander 1974). This procedure is generally followed in Great Plains tree nurseries. A typical procedure is stratification for 60-240 days, sowing in mid- to late-summer, mulching the seedbeds, and keeping them moist through the fall. Germination occurs the following spring when temperatures reach 50° F (Benson 1976). Individual nurseries differ in the type of stratification used, sowing date, and type of mulch used.

Having said all this, I would like to quickly point out that the actual success of applying all of these techniques to germinate RMJ seed has been minimal, typically 20-50% germination. Consequently, seed germination of RMJ is identified as being one of the highest priority problems in Great Plains nurseries. In response to a request for research assistance, the Rocky

[1] Paper presented at the Intermountain Nursery Association meeting [Bismarck, ND August 14-18, 1989].

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Mountain Station contracted research on "Development of pre-germination treatments to best achieve predictable and uniform germination of Juniperus scopulorum in the shortest time" with SWCA, Inc. in Flagstaff, AZ. This paper reports the results of that research.

MATERIALS AND METHODS

The study consisted of two experiments conducted in 1987-88 and 1988-89, which will be presented separately.

Experiment 1

The experiment tested three seed sources, five seed scarification treatments, and six stratification treatments. Mature berries were collected in late October, 1987 from 10-20 trees in Coconino County, AZ, elevation 6840'; Iron County, UT, elevation 6400'; and in Cassia County, ID, elevation 6100'. The locations represented a general north-south transect, well west of the range of Junipers virginiana to avoid any intermixing. Within 30 days of collection, seeds were depulped, floated, and soaked in isopropyl alcohol to remove residues. The seeds were temporarily stored at 50° F and 10% RH until early December.

The seed scarification treatments consisted of: (1) none, (2) seeds dropped in boiling water, then removed immediately from the heat and allowed to stand 24 hrs; (3) seeds soaked in concentrated sulfuric acid for 0.5 hr; (4) seeds soaked in 1% citric acid for 96 hours; and (5) seeds soaked in 30% hydrogen peroxide for 0.5 hr. Following chemical treatments, seeds were stratified in 4-mil zip-lock bags in a 1:1 peat/vermiculte medium that was fully dampened and treated with a fungicide to prevent molding. Stratification treatments (fig. 1) were combinations of warm/moist (86° F 8 hrs, 68° F 16 hrs) and/or cool/moist (38-41° F). Treatments began on December 8, 1987, and germination tests were completed on July 6, 1988.

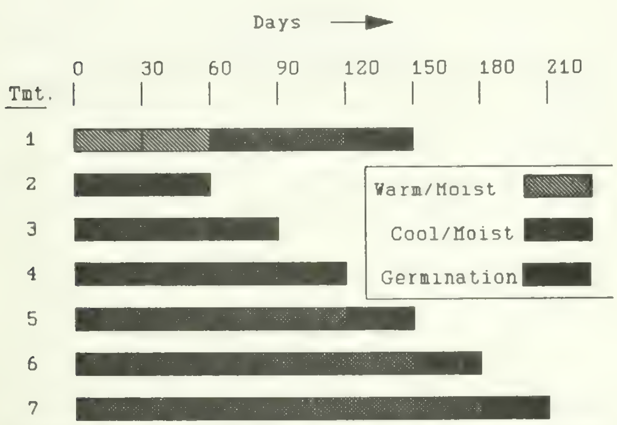

Figure 1. Stratification treatments and schedule for Experiment 1.

When stratification treatments ended the seeds were germinated in flats of 1:1:1 peat/vermiculite/perlite in a greenhouse. Each treatment combination was represented by 100 seeds; there was no replication of treatments. The flats were watered 3-4 times a week. Germination was checked daily for 30 days. Greenhouse temperatures during germination tests differed because of the varying duration of the stratification treatments:

	Jan	Feb	Mar	Apr	May	Jun
Avg.	54	56	60	60	64	69
Max.	67	70	75	74	79	78
Min.	38	45	45	45	51	61
Regime	2	3	4	1,5	6	7

Greenhouse temperature averaged 54-60° F during germination tests for treatments 1-5, and 64-69° F for treatments 6-7.

Experiment 2

The experiment tested four seed sources and eight stratification treatments. All seed was collected in fall, 1988. Seed from three sources was obtained from Great Plains tree nurseries, and the fourth was locally-collected by the contractor. They were: (1) Saguache County, CO, elevation 8500'(obtained from the CO State Nursery); (2) seed zone 600, Meade County, SD (obtained from Big Sioux nursery); (3) Cheyenne River, SD (obtained from USFS Bessey nursery; and (4) Coconino County, AZ, elevation 7000' (locally collected).

Other than depulping and lye-soaking the seed to remove residues, there were no seed scarification treatments in Experiment 2. The stratification treatments (fig. 2) consisted of combinations of warm/moist and cool/moist at the temperatures listed for Experiment 1, and freezing treatments at 5-10° F. Stratification treatments began on December 23, 1988 and germination tests were completed on July 24, 1989.

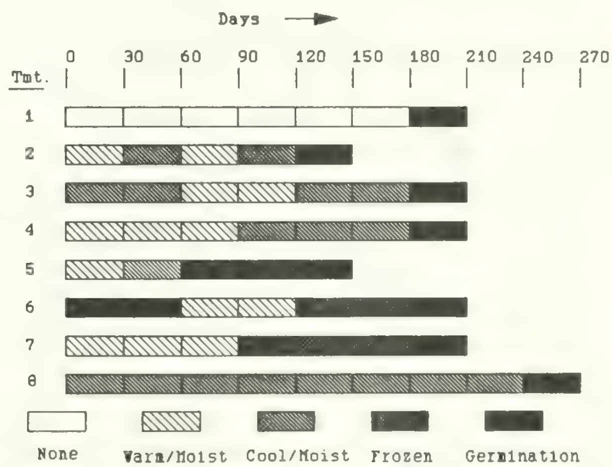

Figure 2. Stratification treatments and schedule for Experiment 2.

Seeds were germinated in the same medium and location as in Experiment 1. Each treatment combination was represented by five flats of 100 seeds. Germination temperatures were 71.5° F for stratification treatments 1-7 and 66.6° F for treatment 8.

RESULTS

Seed germination in Experiment 1 was very low; most treatment combinations had zero germination during the 30-day germination test. The only treatment that resulted in any seed germination was the combination of no seed scarification and warm/moist 60 days + cool/moist 60 days (stratification regime 1). Seed germination was 10%, 1%, and 3% for the Arizona, Utah, and Idaho sources, respectively.

In Experiment 2, samples of the seed were sent to the USFS National Tree Seed Laboratory for viability testing (tetrazolium method) before the stratification treatments were begun. Average percent viability was 70, 57, 82, and 71 for seed obtained from the Colorado State Nursery, Big Sioux Nursery, Bessey Nursery, and locally collected near Flagstaff, Arizona, respectively. Analysis of Variance of germination data and application of Tukey's Studentized Range Test revealed significant differences by seed source and stratification treatments. Treatment effects were the same using percentage germination data based on all seeds or viable seeds. For consistency with Experiment 1, germination data presented are based on all seeds tested.

Effect of seed source

Seed collected in Arizona had significantly lower germination rates than did seeds provided by the Bessey Nursery and Colorado State Nursery (Fig. 3). Germination of Arizona seeds was lower, but not significantly lower, than Big Sioux Nursery seeds. Big Sioux seeds, while lower in germination, were not significantly different from Bessey and Colorado State Nurseries.

Effects of stratification treatment

Stratification treatments 2-8 were not significantly different from the control (treatment 1) (Fig. 4). The lowest germination rate was from treatment 5. The highest germination rate was recorded for treatment 3; this stratification treatment was significantly different from all other stratification treatments.

Seed Source	% Germination	Significance
Bessey Nursery	2.8	
Colo. St. Nursery	2.6	
Big Sioux Nursery	1.8	
Arizona	0.7	

Figure 3. Percent germination by seed source for Experiment 2.

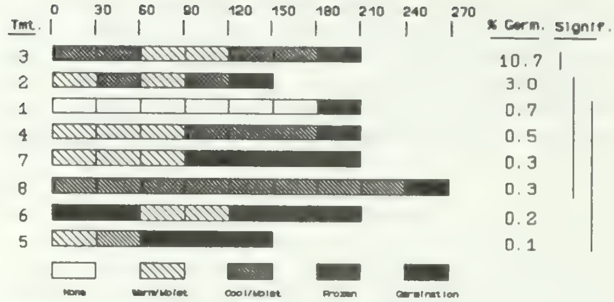

Figure 4. Percent germination by stratification treatment for Experiment 2.

Overall, the highest germination rates were recorded for Bessey Nursery seed (2.8%), and stratification treatment 3 (10.7%).

DISCUSSION

Seed germination was unexpectedly low in both experiments. In Experiment 1, the highest germination (10%) was attained for Arizona seed in stratification treatment 1 (warm/moist 60 days followed by cool/moist 60 days). In Experiment 2, the highest germination (18.6%) was attained for Bessey Nursery seed in stratification treatment 3 (cool/moist 60 days, followed by warm/moist 60 days, followed by cool/moist 60 days). Thus, the pattern was not consistent. Experiment 2 contained three stratification treatments with freezing treatments, which were intended to simulate a cycle of warm and cold seasons, but the resulting germination of seeds subjected to treatments including freezing ranked lowest in the experiment.

The low germination rates in both experiments suggests that some confounding factor was involved. Possible sources of the problem are: (1) collection of immature seed, (2) stratification of seed in plastic bags may have restricted air exchange, and (3) higher germination temperatures may have retarded germination. Collection of immature seed can probably be ruled out since seed obtained from three nurseries in Experiment 2 also had low germination. Restricted aeration from stratification in plastic bags can also be ruled out because 4-mil plastic is sufficiently thin to allow gas exchange (Bonner,1971). However, restricted aeration due to the impermeable seedcoat may be an important factor limiting the effectiveness of stratification, as discussed later. The most likely confounding factor in the experiments is high temperature inhibition of seed germination. Juniper seeds germinate best at 50-55° F, and germination is retarded above 65-70° F (Chadwick 1946, Meines 1965, Wycoff 1961). However, none of these authors specified whether these were average temperatures, or if the inhibition occurs when daily highs exceed 70° F. Average germination temperatures in Experiment 1 were generally favorable through May, however

high temperatues exceeded 70° F as early as February.

In summarizing the results of 10 years of research to enhance seed germination of Utah juniper (Junipers osteosperma (Torr.) Little) and western juniper (J. occidentalis subsp. occidentalis Hook.), Young et al. (1988) reported 10 to 37% germination achievable through various stratification treatments. Variations in substrate, moisture content of substrates, or temperature were generally not effective in enhancing germination. An alternative method of stratification that enhanced germination was prolonged immersion in refrigerated (41° F) water baths where oxygen was kept near saturation in the water by actively bubbling compressed air into the bath. This treatment for 12-14 weeks brought germination up to 43 to 58%. Germination was not enhanced by prolonged soaking in nonaerated refrigerated water. Germination was further enhanced to 64 to 84% by addition of 0.284 m mol L^{-1} of Gibberellic acid to the oxygenated cool water baths. These results suggest that the key factors required to accomplish enhanced germination of juniper seed include: (1) time, because of the restricted permeability of the seed coat and slowness of the processes involved; (2) oxygenation; and (3) a growth promoter.

There are two concepts of seed dormancy that pertain to junipers. A brief discussion of these will assist in understanding the complexity of the problems. The hormone interaction model (Kahn 1975) asserts that dormancy or germination results from the balance among gibberellic acid (GA), cytokinins (CK), and an inhibitor (presumably abscisic acid, ABA). The model assumes that GA is a primary hormone that induces germinative enzymatic processes, and CK and ABA are secondary competitive factors. Cytokinins oppose (i.e. neutralize) the inhibitory effects of ABA. The hormonal balance changes during the after-ripening process, and eventually leads to a condition that allows germination. This may include: (1) the disappearance of ABA, or (2) synthesis of GA and/or CK. The model allows that seeds can be either dormant or capable of germination under several alternative hormonal conditions, for example:

#	GA vs.	CK vs.	ABA --->	Dorm. vs.	Germ.
1	+	+	+		x
2	+	+	-		x
3	+	-	+	x	
4	+	-	-		x
5	-	-	-	x	
6	-	-	+	x	
7	-	+	-	x	
8	-	+	+	x	

This model helps explain many of the anomalous hormonal situations in seeds, e.g. (1) dormancy without the presence of inhibitors (#5,#7), (2) germination in the presence of high levels of inhibitors (#1), and (3) dormancy in spite of high levels of GA or CK (#3,#7,#8). The response to the GA treatments by Young et al. (1988) could have been due to the existence of situations #7 or #8, resulting in germination as in situation #2 or #1, respectively. Their results also suggest that considerable time may be required for the changes to occur.

A second concept of seed dormancy pertaining to junipers is shifts in oxidative pathways (Roberts 1973). The change from dormant to germinating seeds is often accompanied by an increased functioning of the pentose-phosphate pathway of glucose use, an important pathway of respiratory metabolism in seeds. The model asserts that dormancy is caused by the enzyme catalase which causes the destruction of metabolically-derived hydrogen peroxide needed for the oxidation of $NADPH^+$. Dormancy release, resulting from the oxidative inactivation of catalase, would allow the respiratory pathway to function at an accelerated level. The results of Young et al. (1988) could also be explained by this model. The seed coat may restrict the entry of oxygen into the seed; but with high oxygen concentrations, sufficient oxygenation may occur over time to inactivate catalase. Once germination begins, the gibberellic acid is needed for germinative enzymatic processes, e.g. synthesis of hydrolytic enzymes which mobilize stored substrates.

Evidence to date does not support this model, but further investigation is clearly needed. Several investigators (e.g. Hendricks and Taylorson 1975) have reported that compounds such as nitrites and thiourea that inhibit catalase activity are effective in releasing seed dormancy in certain species. Bonner et al. (personal communication) have tested thiourea at 1% and 2% concentrations, with and without added cytokinin, on eastern redcedar seeds, and found that the treatments reduced germination. The concentrations applied were quite high, however, and likely caused germination inhibition from the thiourea. Hendricks and Taylorson (1975) found thiourea concentrations greater than 20 mM were inhibitory, and cautioned against using high concentrations for short periods of time.

A study on changes within the seeds of RMJ during the processes of after-ripening and germination (Afanasiev and Cress 1942) also introduces some uncertainty about the catalase-dormancy model. During stratification at low temperatures they found: (1) a slight increase in peroxidase content, (2) appearance of oxidase, and (3) an increase in catalase activity. During germination, the activity of oxidizing enzymes increased markedly. The increase in catalase activity associated with the completion of after-ripening and germination is the opposite of that asserted by the catalase-dormancy model, but the increase in activity of oxidizing enzymes is consistent.

CONCLUSIONS

Although there were some seed source and stratification treatment effects in Experiment 2, none of the treatments tested in this study effectively enhanced germination amount or timing to be useful in nursery culture.

Virtually every treatment known to seed technology has been tried with seeds of various species of junipers. The majority of experimentation, including the present study, has focused on seed scarification treatments and stratification treatments, with minimal success. What is truly needed is basic research to understand the physiological and biochemical mechanisms responsible for the dormancy. Then we will have the basis to develop treatments to achieve prompt and uniform germination.

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Seed Set and Germination of Eldarica Pine Influenced by Cone Hierarchy[1]

John T. Harrington, John G. Mexal, and James T. Fisher[2]

Abstract.-- Tree and cone hierarchy effects on eldarica pine seed quantity and quality are examined. Hierarchy, or location of cone whorl on a branch, and tree significantly influenced total number of seed/cone, number of viable seed/cone and percent viable seed. Whorl 2 cones, the distal whorl, had 54% more seed/cone and a 65% greater percent viable seed. Percent germination, total germination, G_{50} and number of cones/whorl were not effected by either tree or hierarchy. Relationships between total number of seed/cone and number of seed germinating/cone and percent germination are provided. Potential causes for hierarchal effects are discussed.

INTRODUCTION

Eldarica pine (*Pinus eldarica* Medw. (= *P. brutia* subsp. eldarica)) is a member of the *Pinus brutia* group of mediterranean pines (Spencer 1985). The only naturally regenerating population of eldarica pine occurs from 200 - 600 meters elevation in the semi-arid steppe region in the Russian republic of Georgia (Zimina 1978, Mirov 1967 as cited by Spencer 1985). This species, however, has been introduced to numerous countries in Europe, the middle east and Asia, as well as the United States and Australia (Fisher 1985). Eldarica pine was first introduced to the United States in 1961 in southern California (Spencer 1985).

Eldarica pine is used for Christmas and ornamental trees, and in windbreaks throughout its potential range (fig. 1). Eldarica pine can tolerate alkaline soils (Fisher 1985), high levels of salinity (Manuchia 1986) and demonstrates growth rates comparable to *Pinus radiata* and *Pinus caribaea* when well watered (Fisher et al. 1986). Eldarica pine's polycyclic growth habit and deep root system allow it to fully utilize the long growing seasons and deep soil moisture reserves found in regions of the southwestern United States. Furthermore, tests on the wood properties of eldarica pine indicate it has potential for manufactured wood, paper pulp and fuelwood production (Fisher 1985).

Figure 1.--Potential distribution of eldarica pine in the United States (Fisher 1985).

Russia, Iran, Afghanistan and Pakistan are the leading growers of eldarica pine worldwide. Because of international relations with these countries and the lack of a worldwide seed certification program for eldarica pine, obtaining seed can be time consuming, difficult and expensive. While seed companies in the United States sell eldarica pine seed, seed costs and quality vary dramatically. Costs incurred by local (Las Cruces, NM) nurserymen in 1989 ranged from \$110 to \$310 per kilogram (\$50 to 140/lb) and seed germination varied from 30 to 60% following float sorting of the seed.

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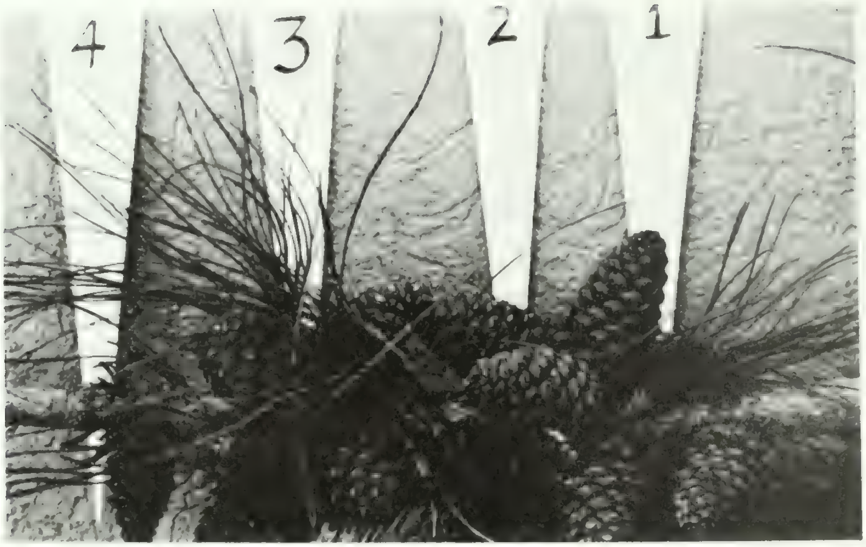

Figure 2.-- Photograph of 4 cone whorls produced on an 17 year-old eldarica pine branch growing in Las Cruces, New Mexico.

Eldarica pine has a relatively unique cone production habit, similar to *Pinus clausa* and *Pinus caribaea* (USDA 1974). Individuals can set multiple flushes or whorls of female cones during one growing season (fig. 2); however, this response is site specific (USDA 1974). This trait affords eldarica pine growers in this region the ability to produce large quantities of seed in a short time (relative to single whorl species). The purpose(s) of this study was to determine if cone heirarchy influenced seed quantity and quality in trees demonstrating this multi-whorl habit, and to examine the tree-to-tree variation in this response.

METHODS AND MATERIALS

Plant Material

Three, 10-year old plantation-grown eldarica pine trees at the Fabian Garcia Science Center in Las Cruces, NM were randomly selected and used in this study. The two most recently matured cone whorls were harvested on two branches of each tree on November 2, 1988. The two whorls of cones per branch were labelled. Whorl 1 was the first whorl of cones produced on the branch; therefore, the whorl closest to the bole of the tree. Whorl 2 was the second whorl of cones produced on the branch during the growing season, and was the whorl closest to the periphery of the crown. No information was taken on the difference in time between cone whorl production.

Eldarica pine has serotinous cones, so seed was extracted by hand using a grafting knife to peel back the cone scales and expose the seed. Total number of seed and total seed weight were recorded following extraction. Total number of seed includes all developed seed and large second year aborted ovules (i.e. pops). According to Bramlett et al. (1977), developed seed can fall into three catagories: filled, partially filled and empty seed (pops). Total seed number does not include first-year aborted ovules (seedless wings) that were observed but not counted. These terms are described in detail by Bramlett et al. (1977) and are addressed in the discussion section of this report.

Germination

Eldarica pine has no reported stratification requirement so none were performed. Following extraction, seeds were soaked for 10 hours in distilled water (25°C). The soaking served two purposes, it separated filled (sinkers) from unfilled (floaters or pops) seed, and allowed the seed to soak up enough water to initiate the germination process. The floaters were air-dried for 48 hours, and their weight and numbers were recorded. These seed were subsequently examined for filling and relatively few (ca 0.7%) were filled.

Filled seed was hand sown in flats of steam sterilized vermiculite, and covered with clear plastic to maintain a moist envirionment. Flats were placed on lab benches where temperatures ranged from 21 to 25°C. Germination was monitored for the next 30 days. A seed was considered germinated when the hypocotyl broke the vermiculite surface. Percent germination, total germination and G_{50} , or date at which 50% of the seed germinated, were determined from this information.

Statistical Considerations

The experimental design was a randomized complete block design with blocking by tree and branches serving

Table 1.--Analysis of variance partitioning of degrees of freedom for the study design.

SOURCE	df
Tree (Block)	2
Whorl	1
Interaction	2
Exper Error	7
Total	11

as repetitions per block. Table 1 illustrates the partitioning of the degrees of freedom of the design. Analysis of variance was performed to test the effects of source (tree) and whorl position on cone number per whorl, total number of seed per cone, total number of viable seed per cone, percent viable seed, mean weight of viable seed, total germination, percent germination and G_{50}. Analysis was performed using the PROC GLM of SAS Version 5 (SAS Institute Inc. 1989).

Regression analysis was performed using number of sound seed per cone as an independent variable on the dependent variables, number of seed germinating per cone and percent germination. Analysis was performed using the PROC REG of SAS Version 5 (SAS Institute Inc., 1989).

RESULTS

Tree significantly impacted both seed quality and quantity (table 2). Among individual trees, tree 2 had both the greatest number of seed per cone, number of viable seed per cone as well as the greatest percent viable seed. Tree 2 also had the highest percentage germination. While not statistically significant (alpha = 0.05), source appeared to influence mean weight of viable seed and G_{50} (PR > F = 0.116). Trees 1 and 3 had comparable numbers of viable seed per cone but total number of seed per cone and percent viable seed differed.

Cone heirarchy or whorl position also impacted seed quantity and quality attributes. Whorl 2 cones, those closest to the periphery of the crown and latest to develop, had significantly greater total seed, number of viable seed and percent viable seed (table 3). Mean weight of viable seed, percent germination and G_{50} were unaffected ($P < 0.05$) by cone position in this study. As was the case with source, whorl position did not influence the number of cones per whorl.

The relationship between the number of germinating seed and total number of seed extracted per cone (fig. 3) is a positive, linear relationship where an increase in the total number of seed per cone yields an increase number of seed germinating. Tree 1 data appear to follow a less steep, positive relationship than do data points from trees 2 and 3. When tree 1 data is dropped from the data set, the model improves with the line becoming steeper and the confidence interval narrowing.

Table 2.-- Mean cone and seed attributes and observed significance levels (**PR>F**) for the three plantation-grown eldarica pine. **Seed Wt. (mg)** = mean weight of sound seed; '-' = tree 1 material failed to reach 50% germination

Parameter	Tree 1	Tree 2	Tree 3	PR>F
Cones/whorl (no.)	3.8	3.3	2.8	0.488
Total Seed/Cone (no.)	54	103	62	0.004
Sound seed/cone (no.)	28.2	71.1	27.5	0.003
Sound Seed (%)	47.7	68.8	38.2	0.050
Seed Wt (mg)	70.7	56.9	61.7	0.116
Germination (%)	24.4	79.8	64.0	0.004
G_{50} (d)	-	12.9	21.3	0.262

Table 3.--Mean cone and seed attributes and observed significance levels (**PR>F**) for whorl 1 and whorl 2 of eldarica pine. **Seed Wt. (mg)** = mean weight of sound seed

Parameter	Whorl 1	Whorl 2	PR>R
Cones/whorl (no.)	3.2	3.3	0.804
Total Seed/cone (no.)	57	88	0.008
Sound Seed/cone (no.)	26.6	58.0	0.004
Sound Seed (%)	38.9	64.1	0.019
Seed Wt. (mg)	64.6	61.6	0.546
Germination (%)	51.1	60.8	0.333
G_{50} (d)	19.5	14.7	0.503

The relationship between germination percent and total number of extracted seed per cone is also positive and linear (fig. 4). However, this relationship is weaker as indicated by the lower correlation coefficient and the wider confidence limits.

DISCUSSION

The relatively large percentages of unfilled seed found in this study may be caused by three agents. First, several insects including seedbugs (*Tetyra bipunctata, Leptoglossus corculus*) attack southern pine cones (Bramlett et al. 1977). Second, attack by several species of fungi can cause unfilled or partially filled seed (Bramlett et al. 1977). A third potential cause for unfilled seed is selfing, or more precisely, homozygous recessive embryonic lethal genes. Most members of the *Pinus* genus have varying numbers of these genes (Bramlett pers. comm.[3]). When this condition occurs, it can result in either a first-year aborted ovule, (i.e. a seedless wing), or a second-year aborted ovule, (i.e. an unfilled seed). A seedless wing is an unfilled seed that never enlarges to full seed size, while an unfilled seed is a full-sized, empty seed

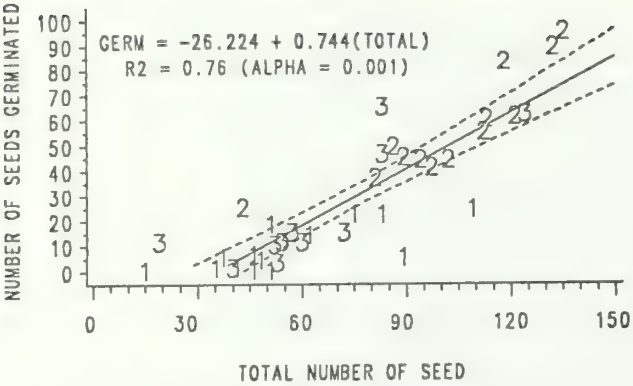

Figure 3.-- Relationship between total number of seed per cone and number of seed germinating per cone. Data points 1, 2 and 3 are those obtained from trees 1, 2 and 3 respectively. Solid line is calculated regression equation and dashed lines represent a 95% confidence limit on the mean.

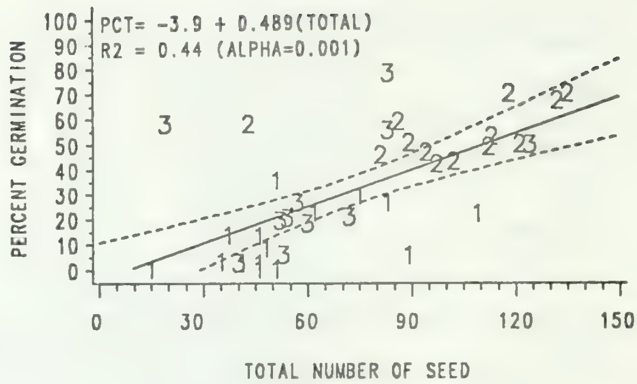

Figure 4.-- Relationship between total number of seed per cone and percent germination. Data points 1, 2 and 3 are those obtained from trees 1, 2 and 3 respectively. Solid line is calculated regression equation and dashed lines represent a 95% confidence limit on the mean.

coat. The material used in this study, while not examined microscopically, had no evidence of insect or fungal attack. This could indicate selfing as the likely cause of the empty seed and the greater percentage of empty seed in whorl 1 found in this study. Possibly, whorl 1 cone receptivity coincides with the time when its own pollen is shed, resulting in greater percentages of selfing in these cones.

The reduced total amount of seed (empty and filled combined) in whorl 1 may be attributable to selfing. Homozygous embryonic lethal genes may result in first-year aborted ovules. Seedless wings were observed in this study, but no data were recorded. If the timing of receptivity for the whorl 1 cones coincided with that of pollen dispersion for the same tree, this may have resulted in first-year aborted ovules, which would have decreased the total seed numbers in this whorl.

A second explanation for the decreased total number of seed in whorl 1 cones may be the result of an overall decrease in the amount of pollination of these cones. While pollen production and cone development timing were not examined in this study, whorl 1 cones possibly were receptive before the majority of pollen production in the stand. This would result in the reduced levels of seed production in these cones.

Cone hierarchy did not statistically impact G_{50} in this study. This may be because of the overall poor germination percentage of tree 1. Only one whorl of cones of this tree exceeded 50% germination during the evaluation period. Overall, whorl 2 seed of tree 1 germinated faster than whorl 1 seed. The approximate 5 days difference between the G_{50}, in the complete data set, of whorl 1 and whorl 2 cones amounts to a 25% decrease in G_{50} of whorl 2 cones.

The number of cones per whorl varied from three to five cones, and was not under any strong heirarchy or tree influence. Most eldarica pine grown in the plantation averaged between three and five cones per whorl. However, eldarica pine can set as many as 20 cones per whorl in southern New Mexico and southeastern Arizona (Harrington and Mexal pers. obs.). It appears number of cones per whorl is primarily environmentally controlled.

As would be expected, tree impacted some of the attributes examined in this study. While eldarica pine is believed to have originated from a relatively small, 550 ha, naturally regenerating stand in Soviet Georgia (Spencer 1985), its genetic base is variable enough to justify the implementation of some screening regieme when selecting potential seed trees.

Number of seed germinating per cone appears to be related to total number of seed per cone. However, this relationship is strongly influenced by tree. As can be seen in figure 3, tree 1 data appear to follow a less steep line than do data from trees 2 and 3. A positive relationship between these variables would be expected becasue more seeds per cone provides more opportunities for seed to germinate. The relationship may afford a grower a criterion suitable for selecting potential seed trees.

The relationship between percent germination and total number of seeds per cone is linear and positive, but is not as defined as the relationship between number of seeds germinating and total number of seeds per cone ($r^2 = 0.44$ vs. 0.76 respectively). While total number of seeds per cone accounted for only 44% of the variation in percent germination, this relationship was unexpected. A possible explanation for this relationship may be that more fertilized ovules result in a stronger carbohydrate sink such that seed vigor improves concomitantly with overall seed set. Shifriss (pers. comm.[4]) found pepper fruit size was positively correlated with number of seed set. Possibly as seed set increases, fruit size increases, and seed vigor, as measured by germination, improves. Further work is needed to identify easy-to-measure attributes that reliably predict seed quality and quantity

[3] Bramlett, D.L. 1989. Personal correspondance. USDA For. Ser. Southeastern Forest Exp. Station, Dry Branch GA 31020.

[4] Shifriss, C. 1989. New Mexico State University Seminar 9/15/89. The Volcani Center, Bet Dagan, Israel.

to be used when selecting potential seed trees. Attributes such as cone length or width may be potential candidates because they are measured easily in the field and may have predictive value.

IMPLICATIONS

Improving seed yields in eldarica pine cone crops may be dependent on supplemental pollination of whorl 1 cones and/or basal pruning seed trees. The majority of staminate cones are produced on the lower one-third of the crown. Removing this pollen source would decrease the likelihood of first and second-year aborted ovules resulting from genetic constraints. If a sufficiently large seed crop is produced, it may be feasible to preferentially collect whorl 2 cones to reduce costs of seed extraction by concentrating efforts and energy on cones with higher proportions of sound seed. Finally, further work is needed to determine the causes of empty seed in eldarica pine, to develop criteria for screening potential seed trees and to understand the influence of cone hierarchy on these criteria.

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Vegetative Propagation of 10-Year-Old Blue Spruce by Stem Cuttings[1]

Anne M. Wagner, James T. Fisher, and Greg A. Fancher[2]

Abstract-- Techniques for vegetative propagation of 10-year-old blue spruce (*Picea pungens* Engelm.) by stem cuttings were investigated. Month of collection of the cuttings and application of rooting hormones were examined. In addition, cutting position, cutting length and caliper were examined in relation to rooting response. December was the best collection date for rooting and root production. No hormone and 2500 ppm indole-butyric acid resulted in the highest rooting response. Hormone level and collection date interacted on root fresh weight. Shorter cuttings and cuttings from the lower two-thirds of the tree were more likely to root.

INTRODUCTION

Blue spruce (*Picea pungens* Engelm.) is used throughout the United States, primarily as an ornamental but also as a Christmas tree. The blue spruce's attractive natural form and broad ecological adaptiveness have made it a valuable ornamental. The natural range of blue spruce extends from southern Idaho to southern New Mexico. Hanover (1975) identified New Mexico sources as among the best for color development and rapid growth. Because distinct geographic ecotypes exhibit variations in form color and growth rates, which do not always breed true to type, the ability to vegetatively propagate superior trees would be advantageous in a tree improvement program.

Variable success has been reported in attempts to vegetatively propagate blue spruce. Hanover (1975) successfully rooted 85% of cuttings from seedlings 30 to 60 cm. tall. Rooting success of cuttings from 1-year seedlings varied from a low of 10% to a high of 80% (Struve, 1982). Thimann and DeLisle (1939, 1942) achieved 80% rooting success with cuttings taken in April from trees 10 to 20 years old. However, they had less success in November and no rooting in other months. Cultivars of blue spruce appear to root more reliably when cuttings are taken in January than in the summer months (Iseli and Howse, 1981). These differences may be the result of different growing environments and tree age. The consensus among growers appears to be, cuttings should be taken in late winter or early spring, and treated with rooting hormones to for maximum rooting response.

Seasonal variation in rooting response is a major factor in vegetative propagation. Season obviously plays a role in physiological conditioning of the stock plant, which in turn, affects the rooting response of the cutting. Lanphear and Meahl (1963) found root-forming capacity of cuttings from two evergreen species was seasonal, peaking in late fall and winter. This relationship could not be altered by the application of an exogenous root-promoting auxin. Norway spruce rooted best when cuttings were taken in April and May, just before or during budbreak (Girouard, 1975). The second best rooting was obtained from cuttings taken in October to November, when bud dormancy was not yet complete.

Unlike some species with preformed root initials, rooting in conifers requires the synthesis of root primordia. Endogenous factors are known to play a role in root primordia formation as well as root initiation and development. Smith and Thorpe (1975) identified two stages when the presence of auxin is essential in root initiation and development. The first stage is marked by the initial events leading to meristematic locus formation, and the second by events immediately preceding meristemoid development. A commonly accepted practice in vegetative propagation, particularly with the more difficult-to-root species such as conifers, involves the application of root-promoting hormones to compensate for a possible lack of endogenous levels of auxins.

In addition to differences in rooting ability described above, within tree differences are also seen. A phenomenon associated with aging is that tissues found at different locations on the same tree differ in juvenility. Paradoxically, tissues at the top of the tree are vegetatively mature, but are the youngest tissues in chronological age. Conversely, the oldest tissues found near the base of the tree tend to be more juvenile (Kester, 1976). Rootability has been related to crown position effects occurring in juvenile seedlings as well as sexually mature trees. Phillion and Mitchell (1984) found cuttings from the lower two-thirds of 15-month conifer seedlings rooted somewhat better than those harvested from higher positions, regardless of clone. However, the effect of

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crown position on rootability was most pronounced among clones yielding rootable cuttings exclusively from the lower one-third of the crown. It was speculated, because this clone was the tallest, it might be less juvenile and the drop in rooting the result of this difference in height, and perhaps greater maturity.

The objectives of this study encompassed several aspects, most of which involved techniques of propagating blue spruce. The primary objective was to determine if rooting success of cuttings differed among several collection dates. Secondary objectives included quantifying the effects of rooting hormone and their effect on root initiation and development. Tertiary factors of interest were the effect of cutting position, initial cutting length and basal stem caliper on rooting response.

MATERIALS AND METHODS

Stock plants were selected from a blue spruce provenance study planted in 1978, at the Mora Research Center, Mora, New Mexico. All trees were unsheared and the plot was thinned to a 1.7 m by 2 m spacing the previous year. No fertilizer had been applied during the previous growing season, but had been uniformly applied in 1985.

Because of the number of cuttings available from each tree, six collection dates were selected in an attempt to identify optimum collection date. Previous work conducted elsewhere (Hanover 1975) indicated blue spruce roots best from late winter to early spring. Collection dates were selected to permit harvest at 4-week intervals beginning in December 1986. Cuttings were harvested: December 20-21, 1986; January 17, 1987; February 14, 1987; March 13, 1987; April 19, 1987; and May 8, 1987.

Indolebutyric acid (IBA), a synthetic auxin, was used to determine if rooting potential could be altered by treatment with exogenous auxins. Three hormone levels were selected along with a control (no hormone). The four treatments were control, 2500 ppm IBA, 5000 ppm IBA and 10,000 ppm IBA.

Each tree was randomly assigned to one of the four hormone levels initially. The study required 12 cuttings from each tree. Cuttings harvested from each tree at the assigned intervals received the same hormone treatment throughout the course of the study to eliminate tree-to-tree variation. Two cuttings were taken from each tree at each collection time. For each collection, 240 cuttings were stuck, with 60 cuttings for each hormone level. A total of 1440 cuttings were used in the study.

Cuttings were harvested in the same manner each collection. Entire primary lateral shoots with terminal buds were harvested. Cuttings included only the growth produced the previous growing season. Tree height was recorded for each tree before cuttings were taken. As each cutting was taken, the vertical distance between the ground and the point of stem severence was recorded (cutting height). In the laboratory, the basal end of the cuttings were recut at a 45° angle, and old wood, if present, was removed. Initial cutting length and basal stem caliper were measured and recorded after recutting. Cutting lengths varied from 3.7 cm to 12.5 cm; all cuttings longer than 12.5 cm were cut at 12.5 cm. Needles were not stripped from the base of the cuttings.

Cuttings were then treated with a 5-second quick dip of the stem basal 2 cm in the preselected hormone treatment. The three hormone treatments containing indolebutyric acid (IBA) were dissolved in 50% isopropyl alcohol. Control cuttings were dipped in a 50% alcohol solution. After drying for 10 minutes; the basal portion of the cuttings were dipped in a 1:1 Captan fungicide/talc mixture. Treated cuttings were immediately stuck in 160 cm^3 polyethylene containers (Ray Leach tubes) containing a 1:1 vermiculite/ perlite mix (v/v), to a depth of approximately 2.5 cm.

Cuttings were then placed on a propagation bench, which was a mist bench system with bottom heat. The mist bench is a modification of the wet tent system designed by Whitcomb et al. (1982). Bottom heat was provided by a Biotherm® heating system at 20°C.

Relative humidity was kept high by the using two independent systems to apply moisture to the bench. A 100% polyester fabric draped over a pitched metal frame attached to the top of the bench provided the enclosure for maintaining relative humidity. The polyester fabric allowed air to circulate through the tent walls while keeping the humidity high. An automated track-mounted boom located 1.0 m above the bench was controlled by an automatic clock timer. The boom contained nine fan-type nozzles to provide uniform mist to the cuttings. Speeds and frequency were adjusted as needed to maintain humidity 65% +/- 10%. In addition, a fog system above the tent was controlled by an evaporative leaf moisture meter. The fog system kept the tent wet and helped maintain the humidity in the propagation bench. Cuttings were fertilized with Hoaglands complete nutrient solution applied with a hand applicator. Cuttings were fertilized three times a week to compensate for the effects of leaching from the mist applications.

Cuttings were removed from the bench after 20 weeks. Treatment blocks were removed individually, and all measurements were made within 72 hours of removal from the bench. If cuttings were removed in advance of evaluation, they were placed in a walk-in refrigerated cooler at 4°C. All cuttings were destructively sampled.

For each cutting the following attributes and measurements were recorded:
Cutting condition; dead, alive, callused or rooted; shoot elongation; shoot measurements; shoot length, shoot caliper, and shoot green weight;
root measurements; primary root number, primary root length, secondary root number (total), secondary root length (sum), tertiary root number (total), tertiary root length (sum) and total root fresh weight (primary and associated root total).

Primary roots were defined as originating from the cut end of the cutting, or callus tissue (if present). After evaluation, cuttings and roots were oven-dried at 65°C +/- 3°C for 60 hours.

The experimental design was a split-plot design. The whole plot treatment design was a 3 (source) X 4 (hormone) factorial. Collection date was the split factor. Cutting height to tree height ratio, final cutting length,

basal stem caliper and cutting fresh weight were used as covariates. Statistical analyses were done using analysis of variance techniques (GLM, SAS Institute, 1985). Range tests were done using the Student-Newman-Keuls test. Discrete data were analyzed using categorical model analysis (chi-square tests) and logistic regression. For analysis, the total number of primary roots was used for each rooted cutting. Root length and root fresh weight were totaled to give a single value for each cutting. Height ratio was a variable created by taking the ratio of cutting height over the total tree height.

RESULTS

Rooting response

After restricting cutting condition classification to only two categories, rooted and not rooted, a categorical model analysis (SAS Institute, 1985) was used to test for significant effects. Overall rooting was low, with 107 cuttings out of 1440 rooted (7%). Collection date and hormone level showed significant effects on rooting response. Collection date was significant with a χ^2 value of 6.26 (probability < 0.0001). By collection date, rooting was highest in December at 15%, followed by 13% in February. There was a drop in rooting in January, and overall rooting declined steadily after February (fig. 1). Hormone level was significant at the 10% level (χ^2 = 6.26; probability = 0.0996). Best treatments were the control and 2500 ppm IBA with rooting percentages of 9% and 11%. Rooting success dropped at the higher levels of IBA (fig. 2).

Logistic regression was used to analyze rooting response in relation to height ratio, initial cutting length, initial caliper and initial fresh weight. The natural logarithm of the ratio of the probability of not rooting over the probability of rooting (called the logit response) was used as a response, and the slope and intercept of the

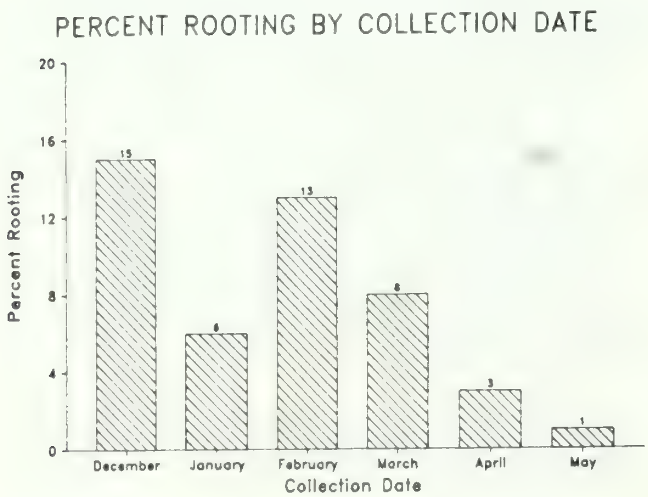

Figure 1.--Percent rooting of blue spruce cuttings by collection date. Based on 240 cuttings/collection date. χ^2 = 6.26, PR < 0.0001.

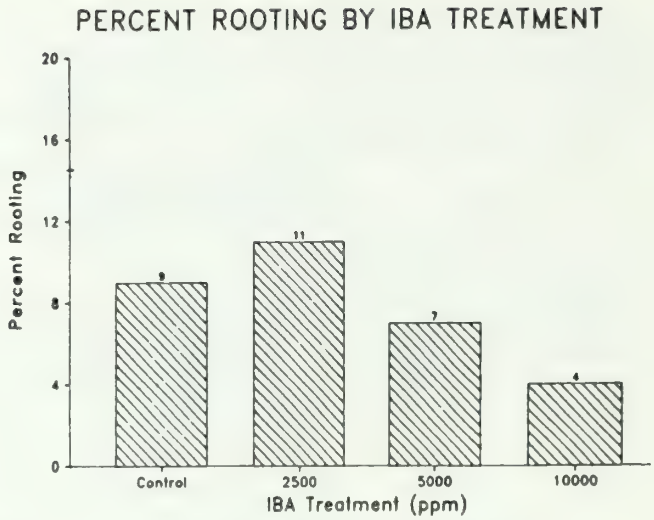

Figure 2.--Percent rooting by hormone treatment of blue spruce cuttings. Based on 360 cuttings/treatment. χ^2 = 4.65, PR < 0.0979.

line representing the relationship were calculated. Only height ratio and initial cutting length had detectable effects on rooting response. The relation between rooting and height ratio was seen when the height ratio data was transformed into categorical data (table 1). Vertical position of the cutting on the tree did influence rooting success. The chi-square test of independence showed rooting and cutting height are not independent factors. Cuttings from the lower third of the tree had rooting rates that exceeded the expected value.

There was a significant relation between initial cutting length and rooting (χ^2 = 54.95, probability < 0.0001). This relationship was positive and had a slope of 0.337, so as cutting length increased the probability of rooting decreased (fig. 3). Probabilities of rooting were generated using this relationship. For the shortest cutting, 3.7 cm, the estimated probability of rooting was 40%. The probability of rooting dropped significantly to 3% as cutting length increased to a maximum of 12.5 cm.

Table 1.--Frequency of rooting by height ratio. Height ratio = cutting height/tree height.

	Height ratio		
	0 - 0.33	0.34 - 0.66	0.67 - 1.00
No rooting			
Observed	29	696	608
Expected	35	702	596
Rooting			
Observed	9	62	36
Expected	3	56	48

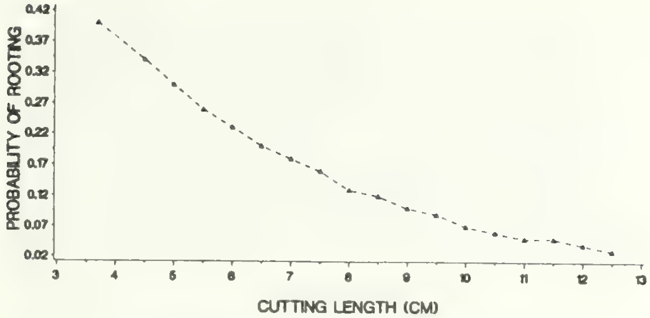

Figure 3.--Logistic regression of probability of rooting and initial cutting length (cm). LN (P0/P3) = -0.8317 + 0.3369 * (X). P0 = Probability of not rooting, P3 = Probability of rooting, X = initial cutting length.

Root analysis

For the analysis of root data, three variables were used as indicators of root quality. Root fresh weight, number of primary roots and root length were analyzed. Because of low rooting response for the April and May collections, those dates were omitted from further analyses of root data. Root data were analyzed using GLM (SAS Institute, 1985). Due to the small number of rooted cuttings, normality assumptions were not met and, while significant affects may be determined, p values may not be accurate.

Root fresh weight

Differences in root fresh weight were detected among collection dates. Root fresh weight was analyzed using the Student-Newman-Keuls test. December cuttings showed greater mean root weight than the other collection dates, which did not differ significantly. December cuttings had a mean root fresh weight of 0.124 g. The mean fresh weight for cuttings taken in March was 0.055 g, and 0.053 g for cuttings taken in February. January cuttings had the lowest root fresh weight with a mean of 0.028 g (table 2). Collection dates were significantly different with respect to root dry weight, which followed the same pattern as fresh weight. There were no significant interactions between root fresh weights by hormone level.

Differences were seen in root fresh weight in hormone by collection date (fig. 4). Examining the collection date by hormone interactions, the greatest root biomass production was the December sampling with the control treatment. Among December cuttings, biomass production decreased as hormone level increased. After December, IBA at the 2500 ppm level resulted in greater fresh weight production by treatment until March when 5000 ppm IBA resulted in a slightly higher fresh weight for the cuttings. Rooting among cuttings receiving the 5000 ppm level peaked in March, whereas the control and 2500 ppm IBA peaked in December. Rooting among cuttings that received 10,000 ppm IBA was low for all dates, but increased slightly in February.

Table 2.--Root fresh weight, number of primary roots and total root length by collection date. Numbers are averages of all 240 cuttings/collection date, including cuttings that did not root. Analyzed using Student-Newmans-Keuls test. Means in a column followed by the same letter are not significantly different. (α = 0.05)

Collection date	Root fresh weight (g)	No. primary roots	Root length (cm)
December	0.12454 A	0.6684 A	118.0 A
January	0.02805 B	0.1991 B	38.0 A
February	0.05257 B	0.3673 AB	24.0 A
March	0.05514 B	0.4615 AB	124.0 A

Primary root number

Differences in primary root number were seen among collection dates. Lack of normality was a problem in the analysis because of large numbers of missing values. Differences were seen between cuttings taken in December and January, but no differences were found among December, Feburary and March cuttings, or January, February and March cuttings (table 2). However, mean number of roots did drop for cuttings taken after December. The range test (Student-Newman-Keuls) did not indicate these in total number of primary roots by hormone level. This was probably the result of unequal sample sizes.

Height ratio was the only covariate with a significant effect on mean number of primary roots. The negative slope estimate of -1.61 indicates, as height ratio increased, number of primary roots decreased. Cuttings harvested from positions higher on the tree initiated fewer primary roots.

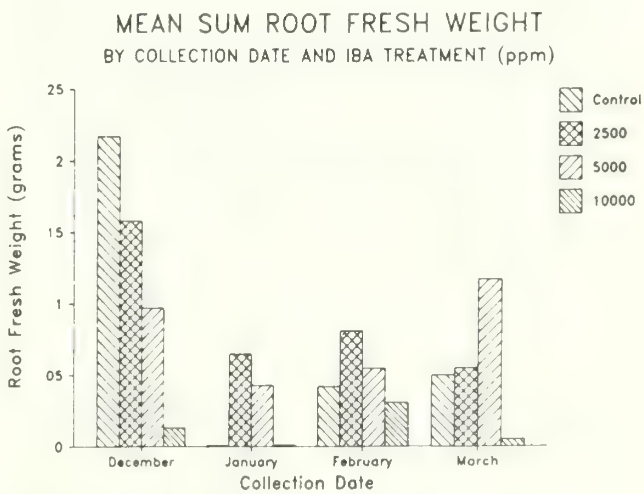

Figure 4.--Blue spruce root fresh weight (g) of all cuttings by collection date and hormone level (ppm IBA).

Root length

Root length for each cutting was analyzed using GLM (SAS Institute, 1985). Differences were seen by collection date, and collection date by hormone level by source. However, the Student-Newman-Keuls range test indicated no significant differences for collection date. This again was probably the reslt of unequal sample sizes. However, examining the means, March cuttings had a mean length of 124 cm., while February cuttings showed a mean length of 24 cm. December cuttings showed a similar response to March cuttings with a mean of 118 cm. January cuttings had a mean root length of 38 cm (table 2). There were no significant differences in root length among hormone levels.

DISCUSSION

Collection date

Although overall rooting success was low, it is possible to root stem cuttings from 10-year-old blue spruce. Collection date was the single factor significant for almost every response variable analyzed.

The best collection date was December, followed by February. The drop in rooting of cuttings taken in January was not expected. The expected rooting percentage was somewhere between the 15% in December and the 13% in February. One explanation is that January was not a favorable time for root initiation in stem cuttings. Perhaps there was some difference among December, January and February which favored root initiation among cuttings taken in December and February but not in January.

Except for the drop in January, it appears the best time to take blue spruce stem cuttings is during winter months, after the chilling requirement has been met (as determined by budbreak in the greenhouse). Rooting dropped off among cuttings collected in the late winter to early spring months, which had been recommended by some researchers (Hanover 1975). These results differ from studies indicating Norway spruce roots well in April and May (Girouard, 1975). However, Fraser fir, as well as other conifer species, roots well in January and February (Hinesley and Blazich, 1984). Thimann and DeLisle (1942) found blue spruce rooted best in April, with some rooting in November. But Iseli and Howse (1981) have more consistent rooting with blue spruce in January.

Hormone level

The best treatment for rooting success was the control followed by 2500 ppm IBA. However, there was little difference between the control and IBA at the 2500 ppm level. In another study with blue spruce cuttings taken in March, there were no differences in rooting responses of cuttings from 10-year trees when treated with no hormone, 2500 ppm IBA or 5000 ppm IBA. Cuttings from 1-year seedlings however, rooted at higher levels, with 100% rooting when treated with 5000 ppm IBA. Cuttings from 15-year old trees, on the other hand, had the highest rooting response (29%) when treated with 10,000 ppm IBA (Wagner unpublished data). Although the collection date by hormone treatment interaction was not significant in terms of rooting success, examination of the data indicates the control treatment in December and 2500 ppm IBA in February are the best treatment by collection date combinations. These results differ from other blue spruce studies indicating higher levels of auxins are necessary to promote rooting (Hanover, 1975; Struve, 1982)

Cutting characteristics

Shorter cuttings are more likely to root than are the longer cuttings. This may be, in part, be related to overall stock plant condition, which favors shoot extension to the detriment of rooting capacity. Farrar and Grace (1942) found some differences in rooting of Norway spruce. They found shorter cuttings may have higher success in rooting, but that shortening longer excised cuttings was of no benefit. Fraser fir, however, showed no effect of cutting length on rooting percentages, but longer cuttings tended to initiate more and longer roots (Miller et al., 1982). The question arises whether rooting success results from the growth form that involves short terminal shoots on the branches, a higher inherent rooting capacity, or a coincidental relationship with cutting length. Another possibility could be that shoot length is a function of crown position.

Cuttings from the lower portion of the tree were more likely to root. Phillion and Mitchell (1984) found similar differences, even in juvenile black spruce cuttings; cuttings from the lower two-thirds of the crown rooted better. There was no significant difference found between cutting stem caliper and cutting fresh weight and the probability of root intitiation in this study.

Root production

Several factors affected root quality. Collection date was significant for all root characteristics analyzed. As discussed above, rooting success was highest among cuttings taken in December, followed by February. December cuttings also showed the highest root biomass production, followed by March. Maximum number of primary roots was highest in December cuttings, followed by February, and root length was greatest in March cuttings, closely followed by cuttings taken in December. Overall, rooting percentages were relatively high for cuttings taken in February, but root quality was less optimal than in December. Considering all the factors of rooting and root quality, an overall recommendation would be to take blue spruce cuttings in December.

Root fresh weight was the only root characteristic to exhibit a significant collection date by hormone level interaction. Root fresh weight changed with hormone level as the season progressed. In December, the highest biomass production was seen with the control level. Cuttings made in January and February showed increased production with 2500 ppm IBA, and March cuttings showed the highest root fresh weight with 5000 ppm IBA.

Conclusions

In summary, the single factor that overrode every variable examined was collection date. Hormone treatment altered somewhat the inherent rooting capacity, but could not completely compensate for non-optimum collection date. Within a tree, cutting position and length do appear to influence rooting success. Overall, a general recommendation for rooting of 10-year-old blue spruce would be to take short cuttings from the lower portion of the tree in December with no hormone treatment. From the results, 10-year-old blue spruce does not appear to be easily mass propagated from field-grown stock plants. However, on a limited scale, such as propagation of superior trees for a breeding program, it would be possible to successfully propagate clones *en masse*, but perhaps with a narrowing of the genetic base.

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Seedbed Mulching with Stabilized Sawdust[1]

John R. Scholtes[2] and Thomas D. Landis[3]

Abstract.-- Discusses the development of a sowing "system" which uses sawdust as the covering for freshly sown seed. Contains a discussion of equipment modifications, material specifications, application techniques, results, and cautions.

MULCHING - BENEFITS AND PROBLEMS

The use of various types of materials to mulch freshly-sown seedbeds is not a new practice. Sand, sawdust, hydromulch, straw, marsh hay, hardwood leaves, pine straw, peat, burlap, thinly-woven cotton, both woven and unwoven poly materials and even plastic sheeting have been used to cover newly sown beds. (Stoeckeler and Jones 1957, Armson and Sadreika 1979). These materials have been used to produce a beneficial environment for seed germination by: controlling erosion from wind and water, preventing soil puddling and crusting, controlling frost heaving, reducing evaporative moisture loss, reducing soil splash, eliminating wicking of saline salts to the soil surface and minimizing surface soil temperature fluctuation. (Stoeckeler and Jones 1957, Armson and Sadrieka 1979, Duryea and Landis 1984)

The general literature dealing with nursery soil management, while mentioning the positive aspects of mulching, actually seems to delve more into the problems which can be associated with the use of mulch materials. Mulches can be expensive to collect or purchase and apply, and some require removal before they cause heat buildup. Others are unstable and blow or wash off the seedbed. Organic mulches can be contaminated with weed seeds or pathogens and may also induce nitrogen deficiency.

Many years of personal experience with mulches and soil amendments have taught that all of the positive as well as the negative statements above can be true. One must be extremely careful when introducing any material into a nursery site.

Seedbed mulches, like any soil amendment, affect the physical, chemical, and biological properties of the soil. Therefore, certain tests are required before any potential mulch material is introduced into a nursery. These include: 1) mechanical analysis to determine particle size and distribution; 2) chemical analysis to test for harmful salts and phytotoxic substances; and 3) biological analysis to look for unwanted and potentially damaging pathogens, seeds, rhizomes, etc.

The addition of a mulch over a seedbed is an amendment to the surface of that seedbed. The key here is the word "amendment". This material will change the condition of the soil and the seedbed. The nursery manager must take those changes into consideration when working with mulched seedbeds. Cultivation of the seedbed surface would destroy the mulch. The rate of application of pesticides, especially herbicides, may need to be adjusted. Irrigation for soil moisture and soil surface temperature control will definitely have to change. And the nursery survival factor will need to be adjusted higher to reflect better survival if the mulched seedbeds are properly sown and managed.

PREVIOUS EXPERIENCES WITH MULCHES

A popular seedbed mulch used at USDA Forest Service Nurseries in the west during the 1960's and 1970's was sand. In the late 1960's, the Coeur de Alene Nursery developed a sand spreader which mulched the entire surface of the seedbed with a uniform thickness of sand. During the early 1970's, two of these spreaders were obtained and used by the Lucky Peak Nursery near Boise, Idaho. Also during the early 1970's, the Mt. Sopris Nursery at Carbondale, Colorado was using a seed drill mounted sand spreader which distributed sand over the individual seedrows. These seedbed mulching "systems" all worked but they also had drawbacks.

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The Coeur de Alene sand spreader mulched the seedbed nicely but required large amounts of clean, relatively dry sand to cover the entire surface. Obtaining clean sand and drying it became a monumental task each spring. Loading and application was slow and the loaded spreader was difficult to maneuver around the nursery and down the seedbed paths.

The Mt. Sopris mulcher required much smaller amounts of sand but the sand had to be perfectly dry and clean to obtain a reasonable flow through the small metering holes and drop tubes. Drying and screening sand and storing it in five gallon containers was a full time spring project for two to three persons.

Over the years, all these nurseries have changed seedbed mulching equipment and even materials. The Coeur de Alene Nursery has gone to hydromulching over a soil cover. The Lucky Peak Nursery has changed to mulching individual seedrows with a commercially packaged sand material.

During the mid 1970's, the authors tested several sowing and mulching systems at the Mt. Sopris Nursery. Two different seed drills were used. The Love-Oyjord[R] utilized disc openers which opened an approximately 0.25 inch wide furrow. The seed was dropped into the furrow. The seed was either covered with soil using concave-shaped packing wheels which pressed the soil back into place or it was left uncovered by removing the packing wheels.

The second seed drill was custom-made and utilized a banded roller. Metal bands were spot welded around the roller, and left impressions for the seedbed rows; the seed was dropped into these impressions. A second banded roller followed the seed drop tubes to firm the seed down into the soil in the bottom of the impression (fig. 1).

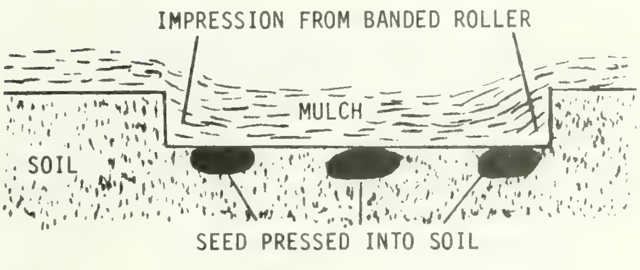

Figure 1.--The placement of seed into a seedrow using a banded roller. Notice that the seed is "firmed" or pressed down into the soil at the bottom of the impression. This is necessary because the mulch material placed over the seedbed will dry out rapidly. However, the soil surface beneath the mulch will remain moist providing a steady supply of moisture for the seed to germinate and the germinant to emerge from the seedbed as a vigorous seedling.

Several combinations of mulching materials were included in the Mt. Sopris trials. They included: covering with soil, sand, two rates of hydromulch, fresh sawdust held in place with hydromulch, and fresh sawdust held in place by staking 60% shade cloth over the seedbed (the cloth was removed at the start of germination). The results of one of these mulch trials has been published (Landis and others 1984).

Of all these trials, the sawdust/shadecloth and sawdust/hydromulch combinations proved superior. The sawdust/hydromulch combination was selected for further operational trials because of the labor of handling the shadecloth. This seed covering system eventually became the standard for operational sowing at Mt. Sopris Nursery.

The authors observed that covering seed with a sawdust mulch which was held into place with hydromulch ("stabilized mulch") had many beneficial effects upon the seedling crop and management of the soil, especially during the germination period:

1. Soil moisture around the seed is more uniform and stable. The mulch dries fairly quickly but moisture in the surface soil will not move into the mulch because of the textural differences between these materials. Another factor that reduces evaporative losses from a mulched seedbed is the insulation provided by the mulch, which lowers surface soil temperatures.

2. Salt accumulation on the soil surface is almost totally eliminated. The mulch slows upward capillary water movement ("wicking") through the soil profile and thus reduces the surface accumulation of soluble salts. High levels of salts at the soil surface bind soil particles into a crust, which can reduce air exchange, increase surface temperature, and reduce water infiltration rates. Also, total soluble salt levels on the soil surface can reach the point of becoming toxic to new germinants.

3. Irrigation requirements are reduced. Reduced evaporative loss from the soil surface significantly reduces the need to add moisture to the soil profile. Except during the germination period and irrigation for cooling or incorporating chemicals, general irrigation can be reduced by as much as 50% during the first year.

4. Improved seed performance because germination and early survival are substantially improved. Seed usage at the Mt. Sopris Nursery was lowered by an average of 20%. Although also affected by other management factors, seedbed mulching played a major role.

5. Improved seedling vigor and root growth. Little comparative data was taken but general observations were that seedlings grown in a mulched seedbed were larger, appeared healthier, and developed larger, more fibrous root systems than those in unmulched areas.

THE NEED AT J. HERBERT STONE NURSERY

These positive experiences with seed mulches were brought by the senior author to the J. Herbert Stone Nursery (JHSN). In the spring of 1986, the sowing practices at JHSN followed standard procedures for covering with soil. The nursery was using two Love-Oyjord seed drills for the majority of the conifer seed. A home-made seeder ("Stone Drill") was used to sow larger seed, such as *Abies* spp., which could not be sown and covered to the proper depth using the narrow disk openers of the Love-Oyjord drill.

The Stone drill was modeled after the Wind River Nursery seeder and had a shoe-type row opener which created an opening just over one inch wide. Although the Stone drill did an acceptable job, it required almost perfectly formed and surfaced seedbeds to allow covering the wide seedrow with the proper depth of soil. The surface of the seedbed had to be pulverized in order to prepare a suitable surface for sowing. The Love-Oyjord drill was also easier to calibrate and operate.

To get away from these problems with the Stone drill, the JHSN nursery staff decided to modify the Love-Oyjord seeder to hand all types of conifer seed. At the same time, the seed drill would be modified to work with a seed mulch.

SELECTION OF A MULCH MATERIAL

Aware that many different materials could be used as seedbed mulches, potential mulches that were locally available at JHSN were evaluated. In order to capture the full range of benefits, the decision was made to mulch the entire seedbed surface. Even though a suitable source of sand was available locally, the cost of procurement and application made this a very costly alternative. The same was true of hydromulch. The most economical material available was fresh sawdust, and so the decision was made to try sawdust as a seedbed mulch at JHSN. This decision was implemented in four phases: 1) Development of sowing equipment, 2) Procurement of suitable quality sawdust, 3) Uniform sawdust application, and 4) Stabilization of the mulch.

1. Development of sowing equipment

One of the Love-Oyjord seed drills was extensively modified to allow sowing the larger seed into wide drill rows and pressing the seed into the soil. Items that were changed or modified are listed below:

a. The smooth drum was replaced with a banded roller: a 1.50 inch wide by 0.38 inch deep steel strap was spot welded around the roller to press indentations into the seedbed surface and form the seedrows (fig. 1).

b. Large drop tubes of clear flexible plastic with an inside diameter of 1.38 inches were fit over the original boots of the seeder (The boots connect the drop tubes to the seed spinner or distribution head).

c. The disc openers were replaced with angled pieces of 1.50 inch muffler pipe bent at the local muffler shop to drop the seed into the rows with minimal bouncing of the seed out of the impressions.

e. The concave soil packing wheels were replaced with flat semi-pneumatic rubber wheels which were 1.50 inches wide to fit down the seedrow impressions and press the seed into good contact with the soil.

f. A seed hopper with a large tube was obtained to allow the large seed to flow into the seedwheel.

g. Larger guages were made to allow the hopper tube to be adjusted to as high as one inch above the seedwheel.

h. The seedwheel was modified by cutting out every other lamelli to allow the seed to drop more freely into the spinner.

i. The funnel between the seed wheel and the spinner was enlarged leaving as large an opening as possible.

j. The chain driver for the seed spinner was replaced with a hydraulic motor drive to allow very slow ground speeds as needed to handle larger *Abies* spp., while still maintaining approximately 800-1200 RPM on the Spinner.

Other "nice-to-have" modifications were also added to the seed drill. These include:

k. A heavy duty digital counter which can withstand more use than the mechanical counters.

l. The seat was offset towards the drive side allowing more room to get on and off the seeder from the left side (facing the rear of the seeder).

m. A step has been built onto the frame halving the distance to the ground.

n. A plexiglass "view window" has been placed into the cover over the gears.

o. The gears have been clearly numbered in the cover.

p. Green and amber lights have been mounted on the tractor with switches on the drill so the drill operator can signal when to stop and go.

q. An insulated box for seed has been built on the front of the seeder.

These modifications have improved safety, operation convenience, and seed care.

2. Procurement of suitable quality sawdust

There are several sources of sawdust available in Southeastern Oregon so prices are competitive. Sawdust must be of the proper size and not contain harmful materials (table 1). Past experience at JHSN had shown that poor quality sawdust can create soil conditions which are detrimental to seedling growth and can cause long-term nutrition problems. Wood from some species of trees can contain phytotoxic chemicals, and sawdust (especially "aged" sawdust) from some sources can contain high levels of soluble salts.

Table 1.--Physical and chemical standards developed for sawdust supply contracts at JHSN:

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1. Physical Properties

   A. Particle Size - Must pass through a 2 cm mesh screen. Not more than 45 percent (by weight) will be fine enough to pass through a 2.0 mm mesh screen.

   B. Purity - No more than five percent by weight of foreign material will be allowed.

2. Chemical Properties

   A. Salinity - The electrical conductivity must not exceed 0.5 mmhos/cm. Total bases must not exceed 15 meq/100 grams of sawdust; of these, calcium levels must not exceed 12 meq and sodium levels must not exceed 0.8 meq.

   B. Phytotoxic Materials - Cedar or redwood sawdust are unacceptable.

During procurement, sawdust should never be stockpiled or dumped onto any portion of the nursery seedbed area because leachates from sawdust piles can be washed into the soil. Furthermore, piles can never be completely removed nor can they be uniformly spread. The tires of hauling, loading and spreading equipment will also work undesirably large quantities of mulch material into the soil in the stockpile area. Leachate concentrations and excess mulch material can cause nutrition and possibly other problems in subsequent crops. At the very least, this practice will result in a soil which has been "amended" into an hodge-podge which will be difficult to manage. It is difficult to resist the temptation of reducing application costs by cutting corners but the material must be stored off the production area and applied in a uniform manner to the fields.

3. Uniform Sawdust Application

After a suitable source of sawdust has been procured, the next concern is how to apply the desired depth of sawdust to the seedbed. A general rule of thumb is to cover the seed to a depth of 1.5 to 2 times the seed width. If the mulch layer is too deep it could physically inhibit germination or keep the soil too cool for maximum seedling emergence. Too shallow a layer would not provide adequate protection for the seed. An old adage is that "you have to leave a little seed showing to be sure that you are not sowing too deep". In reality, this is saying "we do not have suitable equipment or control needed to cover seed to the proper depth, so it is better to sow too shallow than too deep". Obviously, any seed drying under the direct rays of the sun is not likely to germinate. Perhaps one of the most valuable benefits of mulching is getting all the seed covered to a suitable depth.

The type of manure spreading mechanism used to spread sawdust at Mt. Sopris Nursery could not be located. A paddle-type manure spreader was modified and remodified many times in an attempt to get uniform covering over the seed. We were able to get a suitable covering for the larger-seeded species which can push through around an inch of mulch if necessary, and so this spreader was used for those species only. We did not wish to risk covering the smaller-seeded species with this unit although a few trials were promising.

A thorough market survey did not yield mulch spreading equipment which would handle the required minimum of 12 cu yds of material and distribute it uniformly. A contract was developed for someone to design and build a unit which would meet our specifications. After having no takers on this contract, we contacted a leading nursery materials handling manufacturer and obtained working drawings of basic materials handling methods. Following these drawings, we set up a few bench tests to determine our needs for belt speeds, opening heights, etc.

Using information gained through those tests, we have radically modified a manure spreader which has successfully applied a uniform layer of mulch over our seedbeds (fig. 2). Some of the major modifications are listed below:

a. Tapered internal walls to bring the bottom of the box down to a width only slightly wider than the seedbed.

b. A special type of conveyer chain in the bottom replaces the standard draper bars.

c. The conveyer runs on a special bottom layer of smooth plastic to reduce friction.

d. An adjustable tailgate has been fabricated into the spreader to allow for infinite adjustment of the opening above the conveyer.

e. The standard gearbox had to be replaced with a heavy duty box which could stand the drag of the conveyer.

f. A slip clutch was added to protect the gearbox and other drive mechanisms.

Figure 2.--A comercially-available manure spreader was modified with a mesh conveyor chain, a smooth plastic deck, and an adjustable tailgate (A); these modifications, plus the proper tractor speed, apply a consistent, uniform depth of sawdust mulch over the sown seedbed (B).

g. Several wide cross braces were added across the bed to buffer the downward weight of the material in the spreader box upon the conveyer.

h. A special undercarriage was built to fit the seedbed paths.

4. Stabilization of the Mulch

Once the sawdust mulch has been applied, the final problem is to keep it in place. Several different types of chemical "stickers" are commercially available. As previously discussed, hydromulch worked very effectively at the Mt. Sopris Nursery. This method of tacking down the sawdust was and still is an excellent option. However, lacking a hydromulch unit and recalling that this process was somewhat slow and labor intensive to mix and spread, led to the search for some other suitable material.

A brochure on a new material called Geotech[R] had recently been received from the Borden Chemical Corporation. This material was listed as a co-polymer resin and was advertised as having been used to bond sandy soils in southeastern nurseries. A call to the Auburn Nursery Cooperative yielded lots of information about the use of Geotech[R] on sandy soils but no information was available about using this material to bond sawdust. Another source had worked with unpigmented latex at the rate of one part latex to 50 parts water on sandy soil but again had no experience with sawdust. Neither source was optomistic about the effectiveness of either material on sawdust.

The decision was made to take the needed risk and extensively test Geotech[R] on seedbeds, along with a spot test of latex and water. The Geotech[R] was minimimally effective, and held most of the sawdust on our seedbeds most of the time. It must be emphasized that Geotech[R] forms only a rather weak bond between the particles of sawdust. Heavy winds, especially those associated with spring thunder storms, will loosen and blow the surface sawdust off the seedbeds. During the past three seasons in which we have used this bonding agent, we have experienced some blowing of the sawdust off parts of the sown area. This has not affected the germination of the seed because the sawdust in the actual seedrow depressions made by the drill has never been lost. This leaves adequate cover over the seed for germination. What is lost, however, is the benefit of having the entire bed surface mulched. In most cases, we have gone back in and remulched the affected seedbeds as soon as we could get back onto the area.

Only the general lack of wind in the Rogue River Valley which lowers the risk of catastrophic loss of covering during germination justifies the continued use of Geotech[R] at JHSN nursery. A much more dependable bonding agent for the sawdust covering in an area of more wind would be hydromulch.

We are still searching for a better bonding material. One other brand of co-polymer resin was tested this last spring but it had so much large particle material in each of two seperate shipments that we could not use it through our sprayer. We have also tried a material used for dust control on roads known as Lignite. This material seriously depressed both rate and total germination.

CONCLUSION

We have four years experience using a stabilized sawdust mulch at JHSN. We have developed the equipment and processes needed to grow seedlings with mulch. Most of the equipment has been modified several times. The change over to using mulch has not been easy but we believe that the payoff has been worth the effort. For instance, we now sow all our seed with just one type of drill which is easy to calibrate and use. Seedbed preparation is faster and we believe easier on the soil. A few small clods, twigs, slightly uneven surfaces are no longer problems. We have also seen payoffs in the seedlings. The first year we sowed Abies with mulch cover, we increased the anticipated survival by 10% and we still came up with surplus seedlings. The disadvantage of course was that we also had overly dense seedbeds. We are still working with our sowing factors and we are definitely sowing less seed per thousand seedlings shipped.

Seedlings are also growing faster than anticipated. This can be both "good" and "bad" from a managers view but having the capability of producing larger seedlings faster allows more flexibility in managing future crops. Root systems are also better developed with more branching of secondary permanent roots were up near the surface of the ground than had been observed before.

This last spring, we converted our second seed drill to utilize this mulching process. We have saved the original drill parts "just in case" but we really doubt that we would ever go back to trying to cover with soil.

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Soil Management Practices at the Big Sioux Nursery[1]

Blaine F. Martian[2]

Abstract: The Big Sioux Nursery was experiencing nutrient deficiencies brought on in part by the increased seedling production. A soil management plan was written to better utilize the resources available and give management a tool in which they can increase the potential and maintain the productivity of the soil.

Introduction

The Big Sioux Nursery has been producing conifer seedlings since 1957 and hardwoods since 1978. In this time period we went from around 600,000 seedlings of 6 different types of conifers to 2 million seedlings of 40 different species. This increased production and in particular the large increase in the number of tree species has placed an accelerated demand on the nursery's soil resource. Hardwood and conifer seedlings generally have different soil requirements and it is therefore important to identify the production potential of all management units.

The Big Sioux Nursery contains 154 acres of which 87.5 acres are into production ground. The land is divided into 18 production blocks varying from 2.5 to 13.8 acres. The majority of the blocks are in 4 acre increments.

Soils Inventory

As far as can be determined no intensive soil survey had been done until this plan was developed in 1982. Up until this survey, soil variation was not considered in the management of the nursery. Trees were sown in areas that had been out of production the longest. We experienced chlorosis, stunting, and irregular beds along with other various nutrient deficiencies. At this time we contacted Tom Landis and it was determined that a soil management plan needed to be written.

The first step in the soil management plan was to survey the soil. The nursery consist of two principal soil types with two inclusions for the nursery. The first soil type, Fordville-Renshaw soils are basically a fine sandy loam underlaid by coarse textured calcareous material. The second type, Egeland-Sioux soils are both finer-textured sandy loams on the surface but differ in subsoil texture. The Egeland subsoil is a heavy loam whereas the Sioux type contains sand and gravel in the subsoil; both are calcareous in nature. (USDA 66)

The second step was an intensive soil survey that was performed in 1982-83 with the USDA Forest Service. The nursery management units were analyzed individually for significant characteristics that would affect their productivity. A series of soil pits were dug in a regular pattern across the units. The analysis consisted of on site measurements of surface and subsurface soil texture, depth of arable soil, occurrence of restrictive layers and subsoil features relating to the presence of calcareous features. Soil samples were also collected from each management unit and one composite sample per unit was sent to Oregon State University for chemical analysis.

Physical and Chemical Soil Properties

As a guideline we used the soil productivity targets for the interior west. (Landis 1983) Soil texture is one of the most important properties of the nursery soil because it affects most other physical and chemical properties and because it is almost impossible to

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modify. The ideal nursery soil texture is a loamy sand or sandy loam. Out of the 18 management units at the nursery, 13 units were classified as loam and 5 as sandy loam. In general, the soil texture in most management units at the Big Sioux are slightly heavier than recommended but should prove to be acceptable for production of tree seedlings. The northern half is more suitable for conifer production than the southern half so this has played an important part in our planting plan.

Soil depth

The depth of the surface soil is important for the development of a good root system as well as for standard soil tillage. Seedling size specifications typically call for a root system that is 8 to 10 inches long and therefore the production soil must be at least 12 inches deep to permit proper lifting. Root culturing practices also occur in this area so the soils need to be deep enough to avoid bringing up calcareous material from the subsoil. Our survey revealed only one management unit "Q" with unsuitable soil depth. There are shallow spots in other areas of the nursery probably attributable to land levelling during nursery development that will have to be managed around.

Soil Reaction

The ideal soil pH for tree seedling nurseries varies from a range of 5.5 - 6.5 for most conifers to a 6.5 - 7.5 range for junipers and hardwoods. At the Big Sioux Nursery, the soil pH values ranged from a low of 6.6 in Unit K to 8.3 in Unit P. The overall objective of pH management at the Big Sioux Nursery is to lower pH gradually to the desirable ranges over a long period of time.

Organic Material

Organic matter levels are very good in all units ranging from 3.1 to 5.1 as compared to the recommended range of 2.0 to 5.0. No additional amendments have been made except for a green manure crop during the fallow year. Electrical conductivity has not been tested regularly because the initial test showed that all units were low. Considering the good internal drainage of the nursery's soil and with proper irrigation, salt buildup should not be a problem.

The cation exchange capacity was initially tested in 1983. The results showed the capacity of all management units at the nursery were very good, ranging from 13.2 to 21.1 meq compared to the recommended range of 7 - 12 meq. This is a reflection of the high organic content of the soil and the clay component of the loam soils. As long as the soil organic material is maintained, there should never be a problem with C.E.C. (Table 1)

Table 1. Physical and Chemical Soil Properties of Management Units at Big Sioux Nursery

Management Unit	Acres	Surface Soil Texture	Surface Soil Depth (in)	pH (units)	E.C. (mmhos)	O.M. (%)	C.E.C. (m.e.)	$CaCO_3$ (%)
A	4.3	Loam	12-15	7.3	0.08	5.1	21.1	-
B	4.3	Loam	12-15	7.5	1.10	4.3	17.0	2.5
C	4.4	Loam	15-20	8.1	0.70	3.1	15.2	3.6
D	4.2	Loam	15-20	7.7	0.60	4.2	19.2	2.3
E	3.9	Loam	15-20	7.4	0.60	3.3	15.9	-
F	4.3	Loam	15-20	7.2	0.40	3.4	14.0	-
G	4.1	Loam	15-20	7.5	0.50	3.8	16.1	1.9
H	4.2	Loam	15-20	7.4	0.90	4.3	18.1	-
I	6.8	Sandy Loam	10-15	7.4	0.35	3.9	14.5	-
J	6.3	Loam	10-15	7.3	0.90	3.5	17.0	-
K	3.6	Loam	10-15	6.6	0.50	3.8	13.2	-
L	4.0	Loam	12-15	7.7	0.60	3.7	14.1	2.3
M	4.1	Loam	12-15	6.8	0.90	3.5	14.9	-
N	4.1	Sandy Loam	10-15	7.4	0.30	5.0	16.6	-
O/P	13.8	Sandy Loam	15-20	7.0	0.40	4.1	14.6	-
Q	2.5	Sandy Loam	5-10	8.3	0.50	4.9	16.6	3.6
R	8.6	Loam	15-20	8.0	0.45	4.1	14.2	2.5

Present Practices

Now that we know what we have we can go about managing our soil to obtain its greatest potential. We began by changing how, when, and what types of fertilizer we used. When one management practice is changed it begins to affect many other areas, which in turn will need attention and is all part of fine tuning the operation.

Once we knew the physical properties of our soil we were able to look at the chemical properties. We concentrated our efforts in 5 areas, nitrogen, phosphorus, potassium, organic matter, and pH. (table 2)

Table 2. **Macronutrient Levels in Management Units at Big Sioux Nursery**

Management Unit	Total N 1/ (%)	P (ppm)	K (ppm)	Ca (meq)	Mg (meq)
A	-	22	105	15.4	5.2
B	-	23	86	15.1	4.3
C	-	20	109	17.0	3.7
D	-	14	90	15.3	.4.7
E	-	13	109	13.5	4.3
F	-	15	105	12.0	3.8
G	-	12	117	14.2	4.1
H	-	22	94	14.8	4.4
I	-	5	51	12.1	3.7
J	-	9	82	13.2	3.7
K	-	21	86	10.3	3.0
L	-	14	78	13.1	3.5
M	-	21	74	10.2	3.0
N	-	8	66	15.9	4.4
O/P	-	5	59	11.4	3.4
Q	-	6	82	28.5	4.2
R	-	3	59	14.4	3.3
Recommended Ranges:		20-50	100-150	2.5-5.0	1.0-2.0

We do not test for nitrogen because the standard test is not a good indicator of what is available for the plants because of the many organic and inorganic forms of nitrogen in the soil. Secondly, the available nitrogen forms are very transient in the soil and can be lost to leaching.

Prior to having a management plan, nitrogen was applied 1 or 2 times a year in the form of ammonium nitrate (34-0-0). We now use ammonium sulfate (21-0-0) at the rate of 150 lbs. of actual nitrogen per acre divided into 5 or 6 applications per year. (table 3)

Table 3. **Yearly Fertilizer Program for Big Sioux Nursery**

Fertilizer	Analysis	Nutrients Supplied	Application Procedure: Rates/Acre	Timing	Method
1. Ammonium sulfate	21-0-0	21% N 24% S	720 lbs at 120 lbs/app'n	6 app'n/yr	top-dressing
2. Concentrated superphosphate	0-46-0	46% P_2O_5	178-478 lbs. 1/	once in fallow year	incorporation
3. Potassium sulfate	0-0-54	54% K_2O 18% S	53-493 lbs. 1/	once before sowing	incorporation
4. Sequestrene 138 iron chelate	0-0-0	6% Fe	48-72 lbs.	once before sowing	incorporation

Phosphorus and potassium levels at the Big Sioux were below the recommended levels in all management units. They were higher in the areas that were under cultivation showing us that the native soils were low in both chemicals. To determine the amount that is needed, we had the soil tested and then determined how much was needed by computing the difference between the soil Phosphorus and Potassium level and the recommended range. Since the tests are calculated in ppm we have to convert the ppm to lbs. per acre. At this time you must convert the P to P_2O_5 and K to K_2O because these are forms in which the fertilizers are rated. Then you must figure in the % analysis, concentrated superphosphate (0-46-0) contains 46% P_2O_5, so you will need to divide by .46 to get the actual rate needed. The recommendation for the Big Sioux nursery was to use triple superphosphate (0-45-0) because of it's high analysis and low gypsum content. Phosphorus is not mobile in the soil, so we try to incorporate the phosphorus into the plow layer during the fallow year or prior to sowing.

Potassium sulfate (0-0-54) is used also for its high analysis, low cost, and acidifying affect on the soil. We incorporate this just prior to seeding. (Landis 1983) In the beginning we had to apply large amount of phosphorus and potassium but in the last few years the amounts have been very minimal. We try to have at least the areas just coming out of production soil tested. We usually take our soil samples in October and have them analyzed at Oregon State University in Corvalis, Oregon.

Organic Matter

The next area of treatment is in maintaining the organic content of our soils. We do this in a couple of ways. We use Piper sudan grass as a cover crop. We sow this in the spring on all areas that will be out of tree production for the year. We will allow this to grow about 3 to 4 ft. and then cut it and stack it for later use as a mulch over the seedbeds. With irrigation we try to get at least 3 cuttings a year. After the final cutting the areas are left until spring to help cut down on winter erosion. In the spring we will then disc these areas and plant. The second way in which we add organic material is by leaving as much as possible of the mulch from the beds in the pathways. This has been very effective plus it cuts down on the weeds in the pathways. By fall this material has deteriorated enough where it causes no problems in the tree lifting operation.

As stated earlier we are also trying to lower the pH of our soils. This management has been done by unit, taking into consideration the planned use for that unit. Since 1983 we have dropped the pH from 8.3 to 6.5 in unit C. Other units have not been as dramatic, but have had reductions of .3 to 1.0 over the years. However, as the land is utilized and concentrated in one area more than another, we will notice the pH gradually start to increase. Again at this time we have concentrated our efforts on the highest pH ground and mainly in areas where the conifers are planted. The present strategy is to apply prills of sulfur at about 800 lbs. per acre during the beginning of the fallow year. We have experimented with liquid sulfur directly over newly planted seedbeds of pine and spruce to get a quicker acidification. At this time we have not determined whether this was effective or not.

Conclusion

By having a detailed soil management plan and being able to follow it,we do not see the nutrient deficiencies, the beds are more uniform, and now that most of the blocks are in the recommended ranges we are not using as much fertilizer. Historically the nursery raised pine, eastern red cedar and Rocky Mt. juniper as a 3-0 seedling. Now we have consistently produced them in 2 years. We are also looking at cutting a year of production on several other species. To try to keep on top of our fertility we try to do soil tests on a yearly basis especially on those areas just coming out of tree production. By soil sampling and testing on a yearly basis we are able to track each block and are able to determine where we need more work. This has taken a lot of the guess work out of fertilizing and has enabled us to fine tune our operation.

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Operational Ectomycorrhizal Fungus Inoculations in Forest Tree Nurseries: 1989

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ABSTRACT. During the past 15 years, the mycorrhizal research and development program has evolved to the practical, efficient, and cost-effective application of the ectomycorrhizal fungus, Pisolithus tinctorius (Pt), in both container and bare-root nurseries. The benefits of Pt in reforestation, mineland reclamation, and Christmas tree production include significant increases in nursery seedling quality (reduced culls), and increased survival and growth in field outplantings. Four types of commercial inoculum are currently available, including vegetative mycelium, bulk spores, spore pellets, and spore-encapsulated seeds. Custom equipment has been developed and is commercially available for the operational application of vegetative inoculum in bare-root nurseries. The demand for custom-grown, Pt-inoculated seedlings for an expanding variety of forest applications continues to increase. Approximately 6.5 million seedlings were inoculated with Pt in 1989 in bare-root and container nurseries in the Southern, Central, and Eastern United States. Technology is being expanded to other ectomycorrhizal fungi, host tree species, forest applications, and geographic locations.

Additional Keywords: Ectomycorrhizae, Pisolithus tinctorius, bare-root nurseries, container nurseries, seedling quality, field forestation, mineland reclamation, Christmas tree production, commercial inoculum types, inoculation techniques.

During the past 15 years, the USDA Forest Service, in cooperation with a number of state and private forestry agencies, has been conducting extensive research on mycorrhizae and their applications in forest tree nurseries, forestation, mineland reclamation, and other related forestry uses such as Christmas tree production. The primary objective of this project has been the practical application of one ectomycorrhizal fungus, Pisolithus tinctorius (Pt), in forest land management. This fungus was selected because of its availability, ease of manipulation, wide geographic and host range, and demonstrated benefits to a wide variety of host trees. Pt is especially tolerant of extreme soil conditions, including low pH, high temperatures, and drought, that frequently either kill or inactivate other less tolerant ectomycorrhizal fungi and their host trees (Marx, Cordell, and others 1984).

During the past 10 years, the Pt ectomycorrhizal research and development program has evolved from the controlled nursery-plot research phase to relatively large-scale operational applications in both bare-root and container seedling nurseries. Ectomycorrhizae fungus technology is rapidly expanding to include additional fungi and tree hosts for a variety of forestation applications throughout the U.S. and in several foreign countries. Operational applications are expanding in the United States (Cordell, Caldwell, and others 1988; Castellano, Trappe, and Molina, 1985; Hung and Molina, 1986; Trappe, 1977), the Phillipines (Bartolome, de la Cruz, and others, 1989), France (LeTacon, Garbaye, and others, 1988), and Canada (Langlois and Gagnon, 1988). Effective Pt inoculum, along with the necessary equipment and technology for successful operational applications in bare-root and container nurseries, is now available to nursery personnel. However, the decision to incorporate ectomycorrhizal fungus inoculations into the nursery management program is shared jointly by the nurseryman and the forest land manager. Therefore, nurserymen, contract tree planters, mineland reclamation specialists, Christmas tree growers, and other forest land managers are challenged to become familiar with and evaluate the benefits and costs of custom-grown mycorrhizal-tailored seedlings.

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Benefits

Pisolithus tinctorius, along with several other ectomycorrhizal fungi, have provided significant benefits for field forestation, Christmas tree production, and mineland reclamation projects. Numerous conifer and a few hardwood species have been artificially inoculated. National container and bare-root nursery evaluations have demonstrated the effectiveness of different formulations of the Pt inoculum on selected conifer seedling species (Marx, Ruehle, and others 1981; Marx, Cordell and others 1984). During the past 15 years, more than 100 bare-root nursery

tests with Pt have been conducted in 38 states. Results obtained from 34 nursery tests showed that Pt inoculated southern pine seedlings had a 17 percent increase in fresh weight, a 21 percent increase in ectomycorrhizal development (Fig. 1), and a 27 percent decrease in the percent of cull seedlings at lifting time (Fig. 2). The few instances of negative results have been positively correlated with such factors as ineffective Pt inoculum, adverse environment, detrimental cultural practices, and pesticide toxicity.

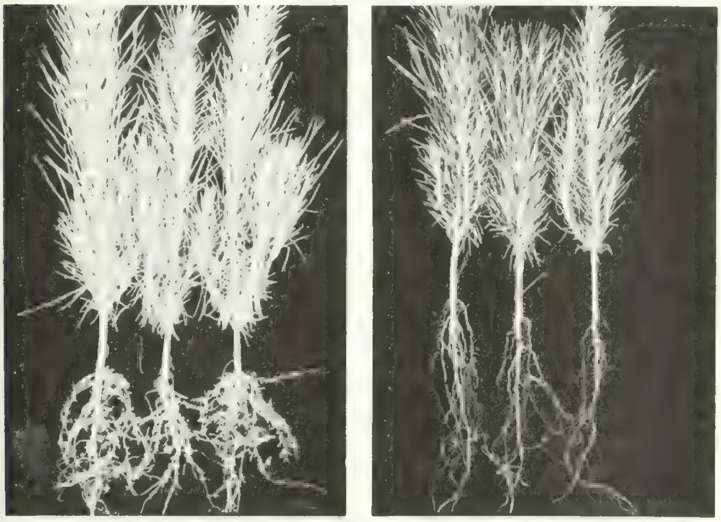


Figure 1. 1-0 loblolly pine seedlings with Pt ectomycorrhizae (Left) and with only naturally occurring ectomycorrhizal fungi (Right)

Figure 2. Effects of inoculation with Pt vegetative mycelium on southern pine seedlings in 34 bare-root nurseries.

Inoculated seedlings have been planted on a variety of routine forestation sites, mineland reclamation sites, kaolin wastes, and Christmas tree farms in locations throughout the United States. Over 100 Pt outplantings involving 12 species of conifers are being monitored in 20 states on a variety of forestation, mineland reclamation, and Christmas tree sites. Preliminary analyses show significant increases in tree survival and/or growth in over half of the 100+ field studies. Pt-inoculated loblolly pines (Pinus taeda L.) show significant increases in tree volume growth, when compared with uninoculated check trees on routine forestation sites in four Southern States (Fig. 3). Positive field responses have been correlated with successful Pt nursery inoculations (Pt index ≥ 50) and with periodic moisture stress. Results from outplanting studies in southern Georgia show that loblolly pine seedlings with abundant Pt ectomycorrhizae at planting date are more capable of withstanding certain site and/or environmental stresses than seedlings without Pt ectomycorrhizae. Rainfall deficiencies have been frequently associated with large growth differences. Results from two studies (Marx, Cordell and Clark 1988; Marx and Cordell, 1988) on routine forestation sites support the theory of greater drought tolerance of Pt-inoculated seedlings. After 4 years on a good-quality, formerly forested site in south Georgia (site index = 80 ft. at age 25), trees with only naturally occurring Thelephora terrestris ectomycorrhizae had significantly less growth during years of low rainfall than Pt-treated trees (Marx, Cordell, and Clark, 1988). During years with high moisture stresses, Pt ectomycorrhizae markedly improved diameter growth. The apparent effectiveness of Pt-inoculated pine seedlings in tolerating moisture stress on routine forestation sites is highly significant and should greatly expand the economic practicality of the Pt program in forest land management.

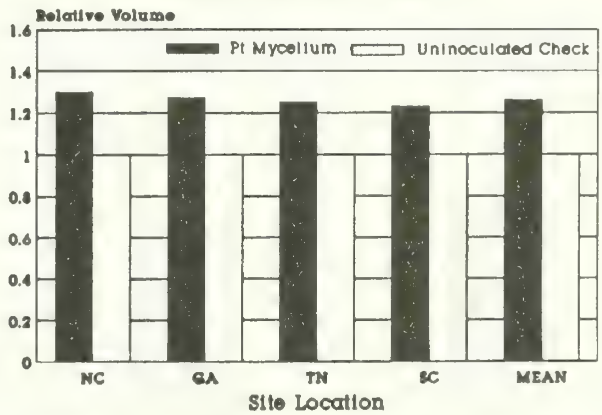


Figure 3. Positive growth responses to Pt inoculation by loblolly pine after 6 to 10 years on routine forestation sites in 4 southern states.

Extensive reclamation research has been conducted on seedlings custom grown with Pt ectomycorrhizae and outplanted on disturbed and adverse sites of various types in the Eastern U.S. In numerous field tests on abandoned mine sites, an-

nual tree root evaluations have confirmed the ecological adaptation of Pt to these adverse sites. Without exception, seedlings with Pt ectomycorrhizae developed new roots very rapidly, and these roots were quickly colonized by the fungus. Root growth was also routinely followed by the prolific production of Pt fruiting bodies in the vicinity of trees with Pt ectomycorrhizae on their root systems. Outplantings established by the Ohio Division of Mineland Reclamation in southern Ohio during the past 7 years continue to show significant tree survival and/or growth increases for Pt inoculated Virginia (P. virginiana Mill.) eastern white (P. strobus L.), and loblolly x pitch (P. rigida Mill.) hybrid pines and northern red oak (Quercus rubra L.) seedlings over routine nursery seedlings (Fig. 4). More recently, Pt-inoculated eastern white and Virginia pines showed increased first-year survival results over uninoculated trees in Christmas tree plantings in North Carolina and Alabama (Fig. 5).

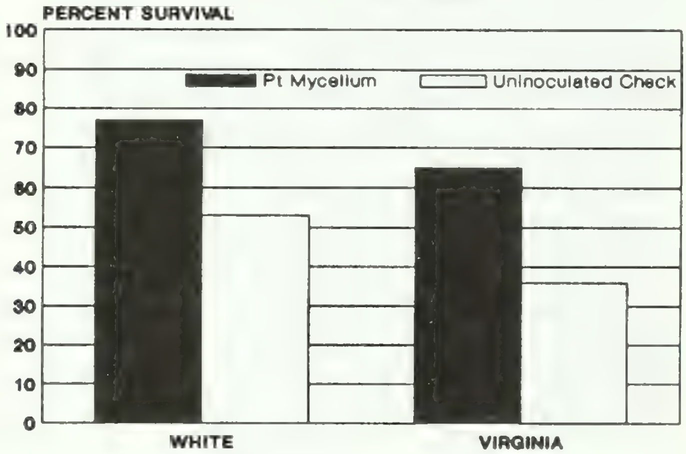
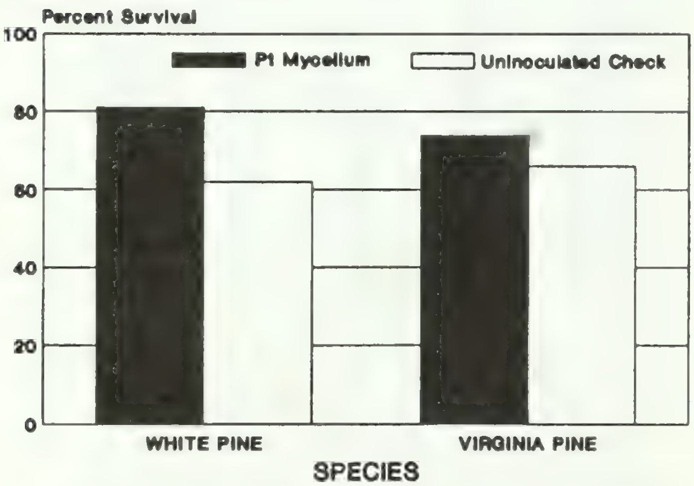


Figure 4. Survival of two pine species on mine reclamation sites in Ohio.



Fiigure 5. Survival of two pine species in two Christmas tree plantings after one year in the field.

Nursery Inoculations

The technology, commercial fungus inoculum, and inoculation equipment necessary to manage the Pt ectomycorrhizal fungus have been developed and are available to nurserymen for operational use. The types of Pt inoculum that are commercially available include vegetative inoculum from Mycorr Tech, Inc., University of Pittsburgh Applied Research Center, Pittsburgh, Pa.; and spore pellets, spore encapsulated seeds, and bulk spores from either International Tree Seed Co., Odenville, Al., or South Pine, Inc., Birmingham, Al. The ectomycorrhizal fungus inoculum applicator has been redesigned with considerable modifications to facilitate the efficient and effective application of Pt vegetative inoculum prior to sowing in bare-root nurseries. Additional improvements in technology and equipment include the development of a machine for side-banding vegetative inoculum between rows of established seedlings. Both applicators are commercially available from R. A. Whitfield Manufacturing Co., Mableton (Atlanta), Ga.

Nursery inoculation procedures vary, depending upon the type of inoculum used. However, with either vegetative or spore inoculum, the biological requirements of a second living organism are added to those of the seedling. As a result, special considerations and precautions are required for shipping, storage, and handling of the Pt inoculum, as well as controlling certain aspects of seedling production, lifting, handling, and field planting. Detailed procedures for handling and storage of the various inoculum types, along with alternative inoculation techniques in bare-root and container nurseries, have been presented (Cordell, Marx, and Owen 1986; Cordell, Owen, and Marx 1987). For successful Pt inoculation in bare-root seedbeds, populations of pathogenic, saprophytic, and native ectomycorrhizal fungi that may already be established in the soil must be reduced. Therefore, soil fumigation before seed sowing (preferably in the spring) with effective soil fumigants comparable to the methyl bromide-chloropicrin formulations is required.

Nursery Management Considerations

Guidelines for mycorrhizal nursery management are designed primarily to promote and maintain healthy seedling root systems (Cordell, Owen, and Marx, 1987). One must consider development and retention of seedling feeder roots and mycorrhizae from the time of seed sowing to seedling lifting in the nursery and subsequent tree planting in the field. Nurserymen, field foresters, reclamation specialists, Christmas tree growers, and tree planters must be made aware of the two symbiotic living organisms

they are handling - the tree seedling and its complement of mycorrhizal fungi.

Mycorrhizae require generally the same moisture, fertility, and pH as their host tree seedlings, but tolerance for extreme or adverse conditions does vary. Soil and cultural factors that significantly affect mycorrhizae include pH, drainage and moisture, fertility, fumigation, pesticides, cover crops, shading and root pruning. Soil and water pH values are two of the most limiting factors in the development of ectomycorrhizae in both bare-root and container nurseries. In addition, seedling lifting, storage, and planting practices have significant effects on seedling feeder root and ectomycorrhizae retention, quality, and subsequent field survival and growth. Special care must be taken during all stages of seedling handling to maintain sufficient root systems and ectomycorrhizae. Ectomycorrhizae are delicate structures that can be ripped off and left behind in seedling beds during lifting, dessicated in storage, or cut off prior to field planting. To sustain seedling quality, lifting and handling techniques must be modified to minimize damage to feeder roots and ectomycorrhizae. Stripping of roots has severe negative impacts on seedling field performance (Marx and Hatchell 1986). Full bed seedling harvesters are generally less destructive on seedling roots and ectomycorrhizae than single- or double-row lifters. During transfer of the seedlings from the field to the packing room and at all other times when the seedlings are being handled, special care is required to avoid drying of the roots by exposure to wind and sun.

The procedure by which seedlings are packed influences their ability to endure storage and survive field planting. If extended refrigerated storage is required, Kraft paper (KP) bags with a polyethylene seal will maintain seedling moisture better than seedling bales. Cold storage is vital to minimize seedling respiration. Studies comparing packing materials have determined that seedling survival is better when peat moss, clay, or inert water-absorbents are used rather than hydromulch (Cordell, Kais, and others, 1984). Numerous studies have documented the adverse effects of long storage time on seedling quality. With notable exceptions for highly sensitive species such as longleaf pine (P. palustris Mill.), however, most tree species can be safely stored under refrigeration for 2 to 6 weeks.

Improper transportation to the planting site or rough handling during planting can also severely reduce seedling vigor. Tree planters should understand proper planting methods and the need for them. Where possible, seedlings should be transported under refrigeration. Otherwise, they should be covered and stacked with spacers to avoid high temperature buildup inside the seedling containers. Insulated storage boxes and heat reflective "blankets" have also been effectively utilized for seedling protection during short-distance transport and temporary storage at the planting site. For machine or hand planting, root pruning at the planting site should be avoided because it eliminates carefully nurtured feeder roots and mycorrhizae. High temperatures, wind, and low humidity dessicate and kill feeder roots and mycorrhizae very rapidly. The first priority in planting should always be to maintain seedling viability and vigor. The rate at which acres are planted is of no consequence if the seedlings do not survive.

Costs

There is a wide range in the cost of commercially available Pt inoculum (Table 1). Inoculum costs of other ectomycorrhizal fungus species, when available, are comparable to Pt. Some nurseries purchase the inoculum and add its cost to the seedling price, while other nurseries prefer that the buyer purchase the inoculum. The Pt vegetative inoculum is sold on a volume basis, while the spore inocula are all sold by weight. The cost of the most expensive vegetative mycelium inoculum ($7.50/1,000 seedlings) represents less than 5 percent of the total plantation establishment costs.

TABLE 1. COMMERCIAL Pt INOCULUM COSTS 1989.

Pt Inoculum Type	Inoculum Costs Per[1] 1,000 Seedlings	Hectare	Acre
Vegetative Mycelium	$ 7.50	$ 13.45	$ 5.45
Spore Encapsulated Seed	2.22	3.98	1.61
Spore Pellets	2.75	4.93	2.00
Double-Sifted Bulk Spores[2]	0:43	0.77	0.31

1-COSTS ARE FOR LOBLOLLY, EASTERN WHITE, AND VIRGINIA PINE BARE-ROOT NURSERIES (269 SEEDLINGS/SQ. M. - 25 SEEDLINGS/SQ. FT.) & FORESTATION PLANTINGS (1.8 x 3.0 M - 6 x 10 FT. SPACING, 1794 TREES/HA. - 726 TREES/AC.) IN THE SOUTHERN AND EASTERN U.S.

2-DOUBLE SIFTING IS REQUIRED FOR EVEN FLOW THROUGH SPRAY NOZZLES. STANDARD SPORES ARE ONLY SIFTED ONCE.

Operational Applications

The demand for Pt-inoculated seedlings continues to increase. In 1988, 6 million seedlings at 12 bare-root and container nurseries in the Southern, Central, and Northeastern United States were inoculated with Pt. In 1989, the total rose to 6.5 million seedlings of eight conifer and one hardwood species (Fig.7).Also, several additional ectomycorrhizal fungus species were commercially produced and operationally utilized in 1989. Annually, since 1987, 1.5 million loblolly and 0.5 to 0.75 million longleaf pine seedlings have been successfully inoculated with Pt and custom grown at the Taylor State Nursery, Trenton, S.C., for forestation plantings at the Savannah

River Forest Station, Aiken, S.C. During each of the 1987-88 and 1988-89 planting seasons, four field demonstration plantings were established comparing various nursery and field treatments, including nursery seedling quality, Pt inoculation, pine species, tree spacing and site preparation. Field measurements of these comparative plantings show significant tree survival increases on Pt-inoculated vs. uninoculated pines. This operational project utilizes 3,500 liters of Pt vegetative inoculum in 35,000 linear feet (6.75 miles) of nursery seedbed annually and is apparently the largest single artificial ectomycorrhizal bare-root nursery inoculation project to date.

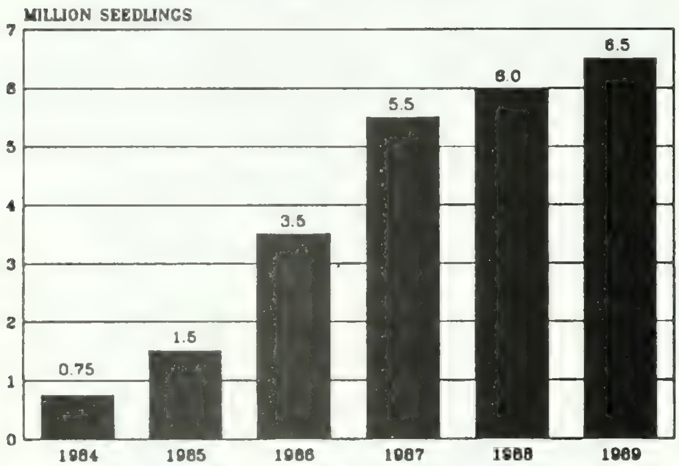


Figure 6. Operational Pt custom seedling production using commercial vegetative and spore inoculum in bare-root and container seedling nurseries, 1984-1989.

Interest in the use of Pt ectomycorrhizae in mineland reclamation has also increased steadily over the past 10 years. Since its inception in 1981, the Ohio Abandoned Mineland Reforestation Program has planted approximately 1.4 million Pt-inoculated seedlings on 810 acres of abandoned minelands in southern Ohio. This program has expanded annually, and in 1988-89 the Ohio Division of Reclamation planted approximately 0.5 million Pt-inoculated seedlings on 285 acres. Estimates for tree planting in Ohio through 1990 indicate further increases of an additional 2.6 million Pt-inoculated seedlings for plantings on 1,850 acres of abandoned mineland (Cordell, Caldwell, and others 1988).

National Forests, state forestry agencies, and a number of private companies have shown considerable interest in the use of Pt ectomycorrhizae on selected forestation sites in the United States. National Forests in Ohio and South Carolina have scheduled the annual production of Pt-tailored bare-root seedlings for selected forestation and reclamation sites. The Savannah River Forest Station, in cooperation with the U.S. Department of Energy (DOE) in South Carolina, has initiated a 5-year reforestation plan utilizing a minimum of 2.0 million Pt-tailored longleaf and loblolly pines annually. During 1989, Pt-inoculated seedlings are being produced for five state forest agencies and five forest products companies. Christmas tree growers have recently ordered Pt-inoculated seedlings, which are presently being produced in several southern nurseries. The demand for Pt-tailored seedlings is expected to substantially increase during the next 5 years due to the increased emphasis on forestation, mineland reclamation and other related forest projects.

Technology Transfer

In a special program, the USDA Forest Service continues to provide mycorrhizae technology to forest tree nurserymen, field foresters, mineland reclamation specialists, Christmas tree growers, and other concerned land managers throughout the United States and several foreign countries (Cordell and Webb 1980; Cordell 1985; Cordell, Owen, and others 1987). Initially, this program emphasized the use of Pt on selected forestation sites and in mineland reclamation programs. However, as previously related, the program is being expanded to a wider range of forestation sites, mycorrhizal fungi, and tree hosts over a broader geographic area. The expanded technology transfer program is acquiring international recognition.

Conclusions

Results obtained during the past several years consistently demonstrate that the Pt ectomycorrhizal fungus can be used operationally in container and bare-root nurseries to significantly improve survival and growth of seedlings for forestation, mineland reclamation, and Christmas tree production. Technology obtained from this pioneering project is being expanded to other ectomycorrhizal fungi, host tree species, forest applications, and geographic locations. Several types of effective Pt inoculum are commercially available, as are machines for vegetative mycelium inoculations in bare-root nurseries. These recent developments provide nurserymen, foresters, mineland reclamation specialists, Christmas tree growers, and other land managers with alternatives for using Pt, as well as other selected ectomycorrhizal fungi. The best field planting results continue to be obtained on adverse sites such as coal spoils and forestation sites with soil moisture deficits. In addition, results are consistently better when planted seedlings have Pt indices $\geq$ 50 (Pt incidence equal to or greater than other natural ectomycorrhizae incidence on seedling feeder roots). The cost of custom seedling inoculations with selected ectomycorrhizal fungi represents only a minor portion of the total tree planting expense (less than 5%), and high seedling quality is an obvious key to suc-

cessful forestation, mineland reclamation and Christmas tree production. Consequently, the benefits of producing custom-grown seedlings with selected ectomycorrhizal fungi for specific forestation and mineland reclamation sites should greatly exceed the costs.

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Bacterial Inoculation of Lodgepole Pine, White Spruce, and Douglas-fir Grown in Containers[1]

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Abstract Inoculation of lodgepole pine and Douglas-fir with two Bacillus strains was shown to promote seedling growth. Strain L6 caused significant increases in lodgepole pine shoot and root dry weight, root surface area, and root collar diameter after eight weeks growth from seed. When 1-0 containerized stock was inoculated, shoot growth was increased, but root weight increases were not significant. Strain L6 also increased the root surface area of Douglas-fir 12 weeks after inoculation. Strain L5 significantly increased the rate of spruce seedling emergence and root surface area of lodgepole pine after 12 weeks growth but dry weight gains were not significant.

INTRODUCTION

Microbial activity in the plant rhizosphere has substantial effects on plant productivity (Gaskins et al. 1985). Bacteria are the most abundant type of rhizosphere microorganism reaching populations of up to 3×10^9 cells per gram dry weight of soil (Rouatt and Katznelson 1961). There have been numerous investigations centred on the possibility of enhancing agricultural crop productivity by inoculating seed or seedlings with beneficial rhizobacteria. Substantial gains in plant biomass due to bacterial treatment have been demonstrated (Gaskins et al. 1985; Schroth and Weinhold 1986). The term plant growth promoting rhizobacteria (PGPR) has been used to describe soil bacteria that are able to colonize plant roots and stimulate plant growth when applied to seeds, tubers, or roots (Kloepper et al. 1980). Seed inoculation with bacteria also has been shown to stimulate seedling emergence (Holl et al. 1988). Strains belonging to several genera have been demonstrated to promote plant growth but those belonging to Pseudomonas, Azospirillum, Azotobacter, and Bacillus are most commonly encountered (Gaskins et al. 1985).

The mechanism by which PGPR exert such effects remains unknown but several possibilities have been examined. These include: (i) increased availability of some limiting nutrient, usually phosphorus, through secretion of phosphorus solubilizing compounds; (ii) suppression of pathogenic or deleterious bacteria in the rhizosphere of crop plants through antibiotic production or direct competition; (iii) bacterial production of plant growth substances such as cytokinins, gibberellins, or

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auxins; and (iv) root-associated fixation of atmospheric nitrogen by diazotrophic microbes (Gaskins et al. 1985; Schroth and Weinhold 1986). Although not conclusively demonstrated, much experimental evidence suggests that bacterially-mediated phytohormone production is the most likley explanation for the acitivity of PGPR (Brown 1974; Tien et al. 1979; Holl et al. 1988).

Canada's productive forest land base of 251 million hectares currently contains 30 million hectares which are classified as not satisfactorily restocked (NSR) (Sutton 1985). Several factors contribute to seedling success in the field but the capacity for rapid and vigorous root growth after outplanting is essential. Inadequate root performance is a common characteristic of failing outplanted seedlings. Because PGPR have been shown to affect root characteristics such as branching, surface area, and biomass (Tien et al. 1979; Chanway et al. 1988a,b) they may be of value in current reforestation efforts.

The possibility of enhancing productivity of tree species by inoculation with bacteria has received little attention, however, growth promotion of deciduous species has been demonstrated (Gardner et al. 1984; Pandey et al. 1986; Caesar and Burr 1987). Only two studies with PGPR and coniferous species have been reported (Parker and Dangerfield, 1975; Pokojska-Burdziej, 1982). In both studies, positive effects due to inoculation were observed but neither study involved pure culture inoculation of seedlings in a standard seedling medium. Therefore, the objective of this study was to determine the effect of pure culture bacterial inoculation on emergence and growth of containerized lodgepole pine, white spruce, and Douglas-fir.

MATERIALS AND METHODS

Seed

Lodgepole pine (*Pinus contorta* Dougl.) was collected near Big Lake, British Columbia (52°22′ latitude, 121°51′ longitude) from an elevation of 945 m. Coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) was collected from McCall Hill, B.C., (52°25′ latitude, 126°11′ longitude) elevation 400 m. White spruce (*Picea glauca* Voss.) was collected near Quesnel, B.C. (53°12′ latitude, 122°3′ longitude) from an elevation of 1350 m. Douglas-fir and white spruce seed was stratified by in cold running water for 24 hours and storing at 4°C for 3 weeks after blotting dry. Lodgepole pine seed was used unstratified.

Microorganisms

Bacillus strains L5 and L6 were utilized as inoculants. These strains were isolated from the rhizosphere of a perennial ryegrass (*Lolium perenne* L.)-white clover (*Trifolium repens* L.) pasture and have been shown to stimulate the growth of various forage species (Holl et al., 1988; Chanway et al., 1988a).

Seedling growth in containers

Experiments were conducted in plastic cones (Pine Cell 64 cm^3, Ray Leach 'Cone-Tainer' Nursery, Oregon, USA) filled with a peat/vermiculite nursery mixture (peat 60 L, vermiculite 20 L, dolomite 190 g, Osmocote 285 g, and micronutrients (Nutritrace, Plant Products Company Ltd., Brampton, Ontario, Canada) 38 g. *Bacillus* strains L5 and L6 were grown separately in nutrient broth for 4 days, harvested by centrifugation (10,000 x g for 15 min) and resuspended in 20 mM potassium phosphate buffer pH 7.0 to a concentration of ca. 10^7 cells per mL (OD_{420}=0.15). Two (lodgepole pine and Douglas-fir) or 4 (white spruce) seeds were sown per cell. Cells were then inoculated with 1 mL of the appropriate bacterial suspension. Control cells received sterile phosphate buffer. Seed was then covered with ca. 10 mm granite grit (No. 1 Granite Grit, Imasco, Surrey, British Columbia, Canada) and cells were watered to saturation.

Seedlings were grown in a growth chamber (Conviron, Winnipeg, Man.) with a 16 h photoperiod, a day night temperature regime of 23:17°C, and photosynthetically active radiation at the canopy level of ca. 300 uE m^{-2}. Plants were watered to saturation every 3 days. Once a week, water was amended with .325 gL^{-1} of fertilizer (Plant-Prod 20-8-20; Plant Products Company Ltd., Brampton, Ontario, Canada) supplemented with 15 mg $FeSO_4$. Each month, 10-15 plants per treatment were harvested. Roots were separated from shoots and shoot height and root collar diameter were measured. Plant material was then dried for 2 days (70°C) before root and shoot weights were recorded and root surface area was assessed using a video image analyzer similar to that described by Cunningham et al. (1989).

Seedling growth in pots

Containerized lodgepole pine seedlings were obtained from the UBC nursery in May and planted in 1 L pots containing greenhouse soil previously described by Holl et al. (1988). Bacillus strain L6 inoculum was prepared as described above. A 1 mL aliquot of bacterial suspension was applied to seedlings above the root system. Control seedlings received sterile potassium phosphate buffer. Plants were grown in the greenhouse under natural light. After 8 weeks growth, seedlings were destructively harvested. Roots were separated from shoots and shoot height, root length and root collar diameter were measured. Plant material was then dried for 2 days (70°C) before root and shoot weights were recorded.

Experimental design and statistical analysis

Experiments performed in containers were arranged in a completely random design and were repeated at least once. Data from experiments were pooled and analyzed as a single experiment with individual experimental trials as an additional factor. A latin square design was utilized in the single experiment involving strain L6 and 1-0 lodgepole pine seedlings. After ANOVA, treatment means were separated using Fisher's Protected LSD or orthogonal contrasts in all experiments.

RESULTS

Strain L6 had a stimulatory effect on seedling emergence of containerized lodgepole pine in one of two trials (data not shown). Five days after sowing, 57% ($p<0.05$) more seedlings had emerged in L6-inoculated containers. The magnitude of the emergence stimulation decreased with time but when emergence was complete 11 days past sowing, L6-inoculated cavities had 12% ($p<0.1$) more seedlings than controls.

After eight weeks growth, seedlings from seed inoculated with strain L6 also showed significant gains in root surface area (23%) and root (17%) and shoot (17%) biomass ($p<0.05$) (table 1). Inoculation with strain L5 did not affect seedling biomass eight weeks after treatment. After 12 weeks growth, no effect of strain L6 could be be detected. However, L5-inoculated seedlings had 16% ($p<0.05$) greater root surface area. Neither strain affected growth of lodgepole pine 16 weeks after seed inoculation.

TABLE 1. EFFECT OF BACTERIAL INOCULATION ON GROWTH OF CONTAINERIZED LODGEPOLE PINE

		ROOT DRY WEIGHT (mg)	SHOOT DRY WEIGHT (mg)	ROOT AREA (cm2)	SHOOT HEIGHT (cm)	ROOT COL. DIAMETER (mm)
8 WKS	CONTROL	18	82	9.8	8.7	0.84
	STRAIN L5	16 (-11)	73 (-11)	8.0 (-18)	9.2 (+6)	NA
	STRAIN L6	21** (+17)	96** (+17)	12.0** (+23)	9.3* (+7)	0.92** (+10)
12 WKS	CONTROL	52	219	21.9	11.9	1.3
	STRAIN L5	51 (-2)	206 (-6)	25.3** (+16)	11.5 (-3)	1.2 (-8)
	STRAIN L6	48 (-8)	224 (+2)	23.3 (+6)	12.4 (+4)	1.3 (0)

* p<0.10   ** p<0.05   ()= % OF CONTROL

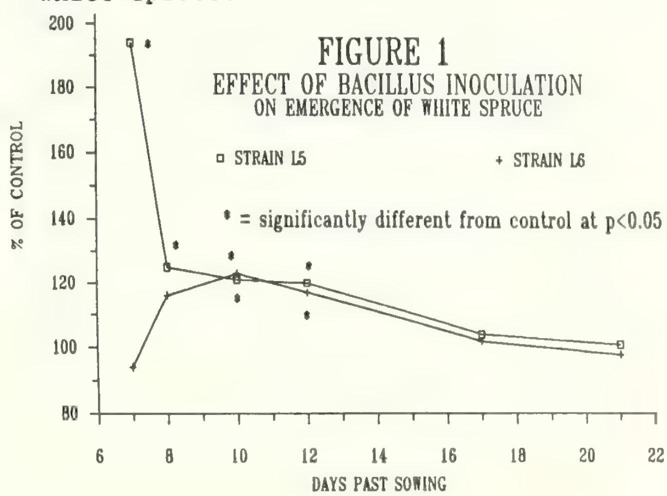
Bacillus strain L6 also stimulated growth of 1-0 bareroot lodgepole pine seedlings when tested in a pot assay in the greenhouse (table 2). Shoot dry weight was significantly higher in response to inoculation with Bacillus (17% $p<0.05$). Root dry weight and caliper also increased due to inoculation, but differences were not significant.

TABLE 2. EFFECT OF INOCULATION WITH STRAIN L6 ON GROWTH OF 1-0 CONTAINERIZED LODGEPOLE PINE

	ROOT DRY WEIGHT (mg)	SHOOT DRY WEIGHT (mg)	SHOOT HEIGHT (cm)	ROOT COL. DIAMETER (mm)
CONTROL	2.23	2.50	16.7	3.82
STRAIN L6	2.46 (+10)	2.93** (+17)	18.0 (+8)	4.01 (+5)

** p<0.05   ()= % OF CONTROL

Inoculation of white spruce with Bacillus strains L5 stimulated the rate at which seedlings emerged (figure 1). One week after sowing, L5-inoculated cavities had almost twice the seedlings (94%, $p<0.05$) when compared with controls. The magnitude of this effect decreased with time until 17 days past sowing when there was no difference between control and L5-treated containers. Strain L6 had no effect on the emergence of white spruce. Neither Bacillus strain affected the growth of white spruce.



Inoculation of Douglas-fir with Bacillus did not affect seedling emergence but significant growth effects were detected. Strain L5 stimulated a significant increase in stem diameter eight weeks after sowing but did not affect plant biomass or root surface area (table 3). Twelve weeks after sowing there were no detectable differences in the performance of L5-inoculated and control seedlings. Strain L6 did not affect seedling growth 8 weeks after inoculation, but a significant increase in root surface area (22%, $p<0.05$) was detected 12 weeks after treatment.

DISCUSSION

Our data confirm that bacterial inoculation of conifer species can stimulate seedling emergence or growth in containers. Uneven or protracted seedling emergence can result in additional costs to nursery operators due to oversowing and thinning operations. Seed inoculation with emergence-promoting bacteria would have obvious benefits in reducing costs associated with poor seedling emergence in the nursery. Bacillus strain L5 stimulated the rate of seedling emergence while strain L6 enhanced the number of lodgepole pine seedlings emerging in one of two trials. These bacterial strains were selected for study because they have shown growth promoting activity with agricultural crops (Chanway et al 1988a; Holl et al. 1988). Other bacterial strains specifically selected for conifer species may be more effective in promoting seedling emergence and require further study.

TABLE 3. EFFECT OF BACTERIAL INOCULATION ON GROWTH OF CONTAINERIZED DOUGLAS-FIR

		ROOT DRY WEIGHT (mg)	SHOOT DRY WEIGHT (mg)	ROOT AREA (cm2)	SHOOT HEIGHT (cm)	ROOT COL. DIAMETER (mm)
8 WKS	CONTROL	28.1	135.5	4.1	9.2	0.84
	STRAIN L5	31.6 (+13)	145.3 (+7)	4.6 (+12)	9.1 (-1)	0.97** (+16)
	STRAIN L6	27.9 (-1)	136.8 (+1)	4.1 (0)	9.2 (0)	0.85 (-1)
12 WKS	CONTROL	91.9	363.0	9.2	17.4	1.45
	STRAIN L5	92.1 (0)	366.0 (+1)	9.2 (0)	18.0 (+3)	1.41 (-3)
	STRAIN L6	102.9 (+12)	390 (+7)	11.2** (+22)	17.1 (-2)	1.55 (+7)

** $p<0.05$ ()= % OF CONTROL

The most consistent effect of seed inoculation on plant growth was an increase in root dry weight and/or surface area. Grossnickle and Blake (1987) have demonstrated the importance of new root growth in establishment of outplanted pine and spruce seedlings. Therefore, bacterial inoculation of seedlings before outplanting may be a useful technique to increase seedling survival in the field.

It is interesting to note that the response of Douglas-fir to inoculation with strain L6 took 3 months to develop. Eight weeks after bacterial treatment no difference due to inoculation could be detected, but 12 weeks after sowing, root surface area was 22% greater than controls. Parker and Dangerfield (1975) also reported a delayed response to microbial inoculation in Douglas-fir. Five weeks after inoculation treated plants were reported to be slightly smaller and weakly chlorotic but 13 weeks after treatment inoculated seedlings were visibly larger. In contrast, the stimulatory effect of bacterial inoculation on the growth of lodgepole pine decreased with time. This may be due to poor inoculum survival or to the restricted area in which root systems developed. Root colonization studies with antibiotic resistant mutants of strain L6, re-inoculation experiments, and experiments in larger size containers are underway to determine the cause of the time dependent decline in growth response. Results from our first re-inoculation experiment indicate that the growth response in pine can be maintained if seedlings are re-inoculated 8 weeks after sowing (data not shown). Further experiments with lodgepole pine, Douglas-fir, and Bacillus strain L6 are underway to determine the field response of seedlings to bacterial inoculation.

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The Effects of Mineral Nutrition on Hardening-Off of Conifer Seedlings[1]

Ivor K. Edwards[2]

Abstract.--Containerized lodgepole pine, jack pine, red pine, Scots pine, white spruce, and black spruce were hardened off under different nutrient regimes to determine the effect of nutrition on development of cold hardiness. There was only weak correlation between cold hardiness and nutrient concentration or uptake in the shoot of seedlings. In lodgepole pine, cold hardiness was associated with a low nitrogen regime and in all other species, it was associated with either high phosphorus or high potassium. The implication of a lower level of cold hardiness achieved in pines is discussed.

INTRODUCTION

Over 30 million containerized seedlings are produced annually in the prairie provinces and annual production is projected to be 50 million in three years.

Overwintering has become a very important phase in the production of containerized seedlings as double- and, in one instance, multiple cropping have become more common. It is necessary if outplanting of the first crop is not possible but it is mandatory in the case of the second or subsequent crop because the latter seedlings have attained their desired size too late in the year for outplanting to occur. In preparation for overwintering, the stock has to be hardened off. Dormancy (i.e., cessation of shoot growth and the initiation of terminal buds) is induced by reducing temperature, light intensity, and photoperiod. Following cessation of shoot growth, budset and bud development occur with a moderate amount of cold hardiness (Glerum 1985). With appropriate low temperature acclimatization, further cold hardiness is developed and the stock is ready for overwintering outdoors.

Nutrition during the conditioning phase to induce dormancy and cold hardiness is believed to be important. Unlike the rapid growth phase, when high nitrogen (N) is required for vegetative growth, low N and high phosphorus (P) and/or potassium (K) are required during hardening off (Levitt 1956). Timmis (1974) found that the level of cold hardiness developed in Douglas fir (Pseudotsuga menziesii [Mirb.] Franco) seedlings was not related consistently to bud development or individual N, P, and K regimes but was more closely related to K/N ratio in the foliage. The use of a finisher-type fertilizer containing low N and high P or K during hardening off is widespread in the seedling production industry in the prairie provinces. However, the practice resulted from advice given by fertilizer companies, based on research with other species and in other parts of Canada. Objective experiments, utilizing prairie conifers, were required. Lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.), jack pine (Pinus banksiana Lamb.), red pine (Pinus resinosa Ait.), Scots pine (Pinus sylvestris L.), white spruce (Picea glauca (Moench) Voss), and black spruce (Picea mariana (Mill.) BSP.), are grown in the prairie region for reforestation and it is necessary to work with appropriate provenances of these species. The objective of this study was to determine which nutrient regimes were associated with cold hardiness in the various conifer species and to determine if specific nutrient concentrations in plant tissue was required for development of cold hardiness.

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MATERIALS AND METHODS

Lodgepole pine and black spruce, jack pine and white spruce, and red pine and Scots pine were grown in the Northern Forestry Centre greenhouse (latitude 53°29' N, longitude 113°32'W) in 1985, 1986, and 1987, respectively. Conifer seeds were sown in peat in Spencer-Lemaire "Fives" containers (cavity volume = 55 cm^3) in February and allowed to grow for 14 weeks (Table 1). Prior to filling the trays, the peat was adjusted to pH 5.2 with calcium carbonate. Environment conditions in the greenhouse were as follows: temperature 24°C day and 16°C night; relative humidity 62-65%; light intensity (high pressure sodium lamps) photosynthetically active radiation (PAR) = 260 mol. $m^{-2}.s^{-1}$

Beginning 21 days after germination, fertilizer solution, recommended for pine and spruce (Carlson 1983) and containing 125mg/ℓ N, 60 mg/ℓ P, and 159 mg/ℓ K, was applied once per week. At fertilization, each cavity was completely saturated with nutrient solution. Other nutrients in the solution prescribed by Carlson (1983) were as follows: iron (Fe), 5.5 mg/ℓ; manganese (Mn), 0.34 mg/ℓ; boron (B), 0.30 mg/ℓ; zinc (Zn), 0.11 mg/ℓ; copper (Cu), 0.02 mg/ℓ; and molybdenum (Mo), 0.01 mg/ℓ. Between the weekly applications of fertilizer solution, the trays were watered as required.

At the completion of 14 weeks' growth, the seedlings were subjected to 12 weeks of conditioning (Table 2) which consisted of an initial two weeks during which supplementary lights were turned off, the trays were leached with water, and allowed to become dry. The drought stress was followed by an initial five-week period during which day and night temperatures were 24 and 16°C, respectively, in the greenhouse and a second five-week period in a growth chamber during which day and night temperatures were 10 and 2°C, respectively. During both five-week periods, a photoperiod of 8 hours was achieved, using a black-out cloth and one of five hardening-off solutions (Table 3) was applied. Solution III was the solution recommended to growers based on a review of the literature. Lower concentrations of N and higher concentrations of P and K were included in order to test their effect on hardening-off.

Table 1. Duration of each phase of the experiments

Phase	Duration
Growth	14 weeks
Conditioning	12 weeks
Cold Hardiness Test	24 hours
Assessment	6 weeks

Table 2. Details of conditioning phase

Time	Condition
Weeks 1-2	Supplementary lights off, leaching, drought stress
Weeks 3-7	Photoperiod 8 hours; Hardening-off solution 1x/wk; Day/night temperatures 24/16°C
Weeks 8-12	Photoperiod 8 hours; Hardening-off solution 1x/wk; Day/night temperatures 10/2°C

Table 3. Nutrient regimes used during the conditioning phase (hardening-off)

Solution	N	P	K
	--------mg/ℓ--------		
I	4.4	101	150
II	22	101	150
III	44	101	150
IV	44	202	150
V	44	101	300

Following conditioning, the seedlings were tested for cold hardiness by placing them in a -5°C or -10°C room for 24 hours. They were then returned to the 10/2°C regime in the growth chamber for 24 h before being placed in the greenhouse for a 6-week assessment. Degree of budset at completion of the conditioning phase was noted and survival and condition of shoot and roots were assessed after 6 weeks in the greenhouse. At the end of the assessment period, the seedlings were measured for height, root collar diameter, and shoot:root ratio (dry weight basis) and foliage was analyzed for N, P, and K. Assessment was conducted on a total of 192 seedlings for each treatment (hardening-off solution), comprised of 4 replicates of 48 seedlings each. Significance of differences of mean survival between treatments was assessed using Student's "t"-test (Steel and Torrie 1980). Correlation between survival and shoot concentration and uptake of N, P, and K, and the ratios N/P, N/K, and K/P was determined using the SAS procedure (SAS Institute Inc. 1985).

Nitrogen was determined by the Kjeldahl method (Bremner and Mulvaney 1982, Tecator 1985) and P and K were determined using ICAP spectrometry after nitric acid digestion (Hogan and Maynard 1984, Kalra et al. 1989).

RESULTS

For lodgepole pine, jack pine, white spruce, and black spruce, survival after cold-hardiness testing at -5°C was high irrespective of nutrient solution applied during hardening off (Tables 4 and 5). At -10°C, survival was associated with certain treatments or hardening-off solutions and were higher in spruce than in pine. Solutions I and III favoured survival of lodgepole pine whereas Solutions IV and V were associated with high survival in black spruce (Table 4). Survival of jack pine and white spruce at -5°C was equally high and was equally low at -10°C (Table 5). Solution IV was best for jack pine and Solution V was associated with highest survival in white spruce. The survival of red pine and Scots pine at either -5° or -10°C was lower than that of other pines in the study and there was a marked decrease in survival of Scots pine, especially, at -10°C (Table 6), indicating that it had developed very little cold hardiness. A summary of the effect of nutrient regime on hardening-off of the conifers tested is shown in Table 7.

Lower survival of pine compared to spruce in the study was correlated with the lower degree of budset observed in pine, following the 12-week conditioning period. White spruce set bud generally within 21 days after drought stress and the 8-h photoperiod were initiated. For black spruce, budset was achieved about five weeks after conditioning had begun. All pines were slower in their response to conditioning. Lodgepole pine and jack pine achieved only 50 and 30 percent budset, respectively, at the end of the 12-week conditioning period. Red pine and Scots pine were slowest to respond to the conditioning treatment and achieved only 10 and 1 percent budset, respectively, prior to the cold hardiness test.

Table 4. Survival (%) of lodgepole pine (LP and black spruce (BS) after cold treatment at -5°C and -10°C

Nutrient Solution	Survival -5°C LP	BS	Survival -10°C LP	BS
I	[1]100a	100a	82a	66c
II	97a	100a	68b	96a
III	100a	100a	78a	85b
IV	99a	97a	39d	100a
V	96a	97a	49c	99a

[1]Within a column, values followed by the same letter are not significantly different at P = 0.05 by Student's "t" test.

Nutrient concentration in foliar tissue was similar in seedlings tested at -5 and -10°C and, except for red pine and Scots Pine, results for -10°C will be discussed.

Table 5. Survival (%) of jack pine (JP) and white spruce (WS) after cold treatment at -5°C and -10°C

Nutrient Solution	Survival -5°C JP	WS	Survival -10°C JP	WS
I	[1]100a	96a	24c	40b
II	96a	88b	20c	21c
III	96a	96a	24c	8d
IV	100a	100a	56a	24c
V	100a	100a	32b	76a

[1]Within a column, values followed by the same letter are not significantly different at P = 0.05 by Student's "t" test.

Table 6. Survival (%) of red pine (RP) and Scots pine (SP) after cold treatment at -5°C and -10°C

Nutrient Solution	Survival -5°C RP	SP	Survival -10°C RP	SP
I	[1]85a	50c	46a	0
II	80a	61b	36b	0
III	71b	54bc	40b	0
IV	80a	56bc	26c	6
V	86a	75a	18c	0

[1]Within a column, values followed by the same letter are not significantly different at P = 0.05 by Student's "t" test.

Table 7. Summary of the effect of nutrient regime on hardening-off of conifer seedlings.

Species	Nutrient regime 1	2	3	4	5
Lodgepole pine	X				
Jack pine				X	
Red pine					X
Scots pine					X
White spruce					X
Black spruce					X

Concentration of N, P and K in shoot was not significantly correlated with cold hardiness as expressed by survival at different nutrient regimes (Tables 4, 5 and 6). The ratios N/P, N/K and K/P in shoot were calculated and they were only weakly correlated with survival after cold treatment. Only in the case of Scots pine was there a high and significant

correlation (r = 0.89) between survival at -5°C and the N/P ratio in shoot. Nutrient uptake in the shoot (determined by multiplying ovendry weight of the tissue by nutrient concentration) was also found to be poorly correlated with cold hardiness.

DISCUSSION

The earlier initiation of budset in spruce, compared to pine, was a reflection of the sharper response (growth cessation) of spruce to a reduction of the photoperiod. The cessation of shoot growth, and formation of a terminal bud signal the onset of dormancy and are prerequisites for the development of cold hardiness (Glerum 1985). Under the conditioning procedure used, the degree of budset in both white spruce and black spruce was higher than in the pines and explains the greater degree of cold hardiness in spruce. Onset of dormancy in pine was obviously not achieved completely prior to the cold hardiness test and, consequently, plant tissue was prone to damage from freezing.

The pines, especially red pine and Scots pine, require further work in determining their requirements of light, temperature, water, and nutrients for hardening-off. Their relatively slow response under the conditioning regime used in this study supports the hypothesis[1], based on fluorescence and photosynthetic studies, that the triggering mechanism for onset of dormancy in pine is completely different from that in spruce, with regard to light and temperature requirements. Pine is able to maintain photosynthesis at lower photoperiod and temperature levels. Also, cold hardiness in roots develops as the growth medium freezes (Glerum 1985). Temperature of the root environment in this study was not monitored but it would not have been less than 2°C, prior to cold treatments. The role of nutrients in the development of cold hardiness is not well understood. In general, nitrogen promotes shoot growth and succulence, thus delaying the development of cold hardiness. Phosphorus and potassium, on the other hand, promote cold hardiness (Levitt 1956). However, research shows no consistent results. Timmis (1974) found no consistent relationship between development of cold hardiness and either bud development or level of N, P, and K in Douglas fir. He concluded that the K/N ratio of the shoot was inversely related to cold hardiness and suggested that a ratio of 0.6 was critical. The weak correlation between cold hardiness and nutrient concentration and uptake in shoot in this study may also indicate that, anatomically, the area of interest is inappropriate. Roots are more sensitive than shoot to damage by low temperature (Steponkus _et al_. 1976) and therefore nutrient concentration and uptake in this tissue should be examined also.

Results from the present study indicate that a nutrient regime with low N was associated with cold hardiness in lodgepole pine, and regimes with high levels of P and K were associated with cold hardiness in jack pine and the other species, respectively (Table 7). Still, inconsistencies remain.

Although Benzian (1965) found a positive effect of K on cold hardiness of Western hemlock (_Tsuga heterophylla_) and sitka spruce (_Picea sitchensis_) in bareroot seedbeds, Christersson (1973) found no effect of K on cold hardiness of potted Scots pine. It is recognized (Glerum 1985) that, biochemically, solute concentration in cells increases as cold hardiness develops and N, P, and K contribute to the accumulation of biochemical constituents, depending on their amounts, relative proportion, and time of application.

Results of this study indicate that the nutrient regime presently recommended for hardening-off of prairie conifer species needs to be revised. The recommendation had been based on a review of the literature (Tinus 1974, Van Eerden 1974) but no work on prairie provenances and cultural practices had been conducted prior to this study.

CONCLUSIONS

Both white spruce and black spruce achieved budset more easily than the pines during conditioning and developed a greater degree of cold hardiness as shown by survival following cold treatment. Cold hardiness in spruce appeared to be related to the degree of budset, generally. The pines, especially Scots pine and red pine, respond more slowly to the stimuli of light and temperature used during conditioning and leads to the conclusion that the mechanism for induction of dormancy in this species is not well understood and is worthy of further research.

Except for Scots pine, the data indicated no significant relationship between degree of cold hardiness and nutrient concentration or nutrient uptake in the shoot of seedlings. Investigation of nutrient uptake in roots also merits further study in view of their lower

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[1]Vidaver, W. 1989. Personal conversation. Department of Biological Sciences, Simon Fraser University, Burnaby, B.C.

resistance to freezing. However, the nutrient regime presently recommended during conditioning (hardening-off) should be amended. Low N enhanced cold hardiness in lodgepole pine, whereas high P and high K promoted cold hardiness in jack pine, and in the other tested species (red pine, Scots pine, white spruce and black spruce), respectively.

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Provenance Differences in Conifer Seedling Variable Chlorophyll Fluorescence Responses Detected Using the Integrating Fluorometer[1]

W. Vidaver,[2] P. Toivonen,[3] R. Brooke,[4] G. Lister,[5] and W. Binder[6]

Abstract.-- Differing from white spruce, Douglas-fir seedlings showed no day length-dependent inactivation of photosynthetic photochemistry. Seedlings of both species show reversible inactivation in response to temperature or drought stress. Provenance differences were observed in the responses of coastal Douglas-fir: high elevation seedlings appeared to be more sensitive to declining temperatures than low elevation seedlings.

INTRODUCTION

In common with other kinds of stress-resistant plants, temperate conifer species regulate photosynthetic activity in response to environmental variations (Pharis *et al, 1970;* Hawkins and Lister, 1985; Strand and Lundmark, 1987; Toivonen and Vidaver, 1988; Vidaver *et al*, 1988; 1989). Several temperate conifers, so far examined in our laboratory, are able to inactivate photochemistry in response to low temperatures or water stress and seedlings of at least one species, white spruce, demonstrate a progressive, daylength-dependent inactivation with the approach of fall (Vidaver *et al*, 1988; 1989). This ability to regulate photochemistry is believed to protect needle chloroplasts from stress-induced photodamage (Bolhar-Nordenkampf and Lechner, 1988; Vidaver *et al*, 1988; 1989). In contrast, daylength-dependent regulation of photochemistry was not detected in seedlings of two coastal Douglas-fir provenance types. However, provenance differences were observed in these Douglas-fir seedlings in the induction of inactivation by low temperatures: seedlings from a high elevation provenance began to inactivate at a higher temperature than seedlings from a low elevation provenance.

MATERIALS AND METHODS

2-0 white spruce (*Picea glauca* (Moench) Voss) and 1-0 coastal Douglas-fir (*Pseudotsuga menziesii*) (Mirb.) Franco) container-grown (PSB-313) seedlings were obtained from the B.C. Ministry of Forests nursery in Surrey, B.C. (approx. 49°08'N, 122°48'W). They were

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then maintained in a growing compound at Simon Fraser University (365 m asl), Burnaby, B.C., until tested. The white spruce seedlot was 8981 (origin 58°N, 120°W, 750 m asl) and coastal Douglas-fir seedlots used were 1273 (origin 49°N 122°W, 152 m asl), 6399 (origin 49°N 122°W, 760+ m asl) and 2968 (origin 49°N 125°W, 670 m asl).

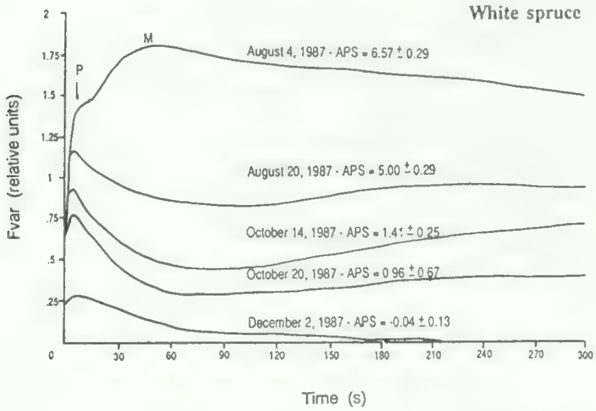

Figure 1.--F_{var} curves for seedlot 8981 white spruce seedlings during progression toward photosynthetic inactivation in 1987. Apparent photosynthesis (APS) shown as mg CO_2/g dry wt./hr. (Redrawn from Fig. 5 in Vidaver *et al*, 1988).

For the fluorescence measurements, shoots of dark-adapted, well watered seedlings were placed in the spherical cuvette of an integrating fluorometer and fluorescence emission (F_{var}) data were collected according to the methods of Vidaver *et al*, (1989).

RESULTS AND DISCUSSION

In white spruce, daylength-dependent inactivation begins around mid-August and usually nears completion by the end of October (Fig. 1). The timing of this progression toward inactivation is somewhat more advanced in higher latitude provenance types than for those more southerly (Vidaver *et al,* 1989). Transient, stress-dependent inactivation can be superimposed on this progression towards winter dormancy (Vidaver *et al*, 1989).

Although photochemical activity in Douglas-fir seedlings fluctuated markedly over the period of July to early December, there was no indication of progression toward fall inactivation (Fig. 2). Presumably, these fluctuations reflect levels of temperature and/or water stress (Vidaver *et al*, 1988) prior to and at the time of measurement.

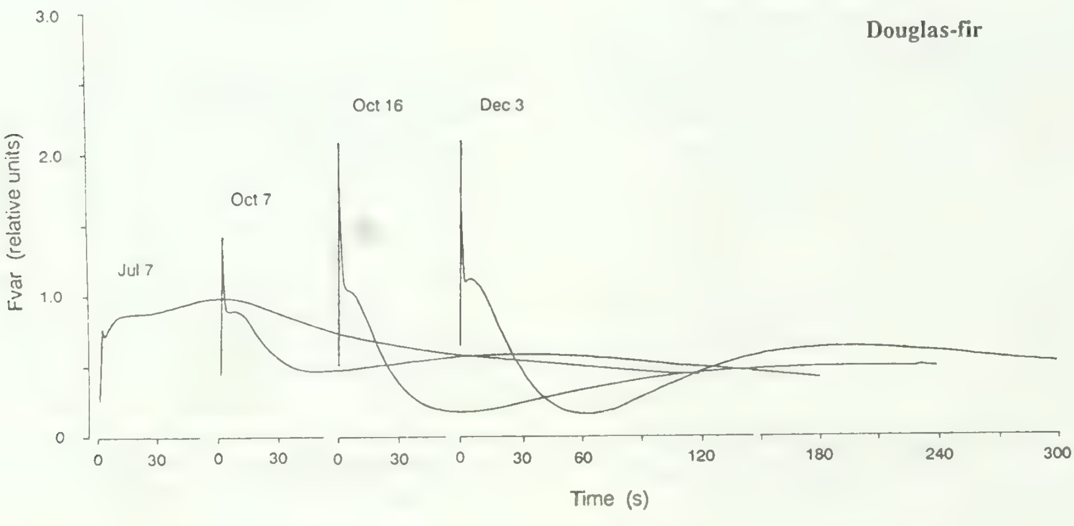

Figure 2.--F_{var} curves for seedlot 2968 Douglas-fir seedlings measured at intervals from early July until early December 1987. Note that except for July 7, the initial F_{var} spike is much more pronounced in these Douglas-fir seedlings compared to white spruce. The July 7 response is indicative of rather severe water stress (see Vidaver *et al*, 1988).

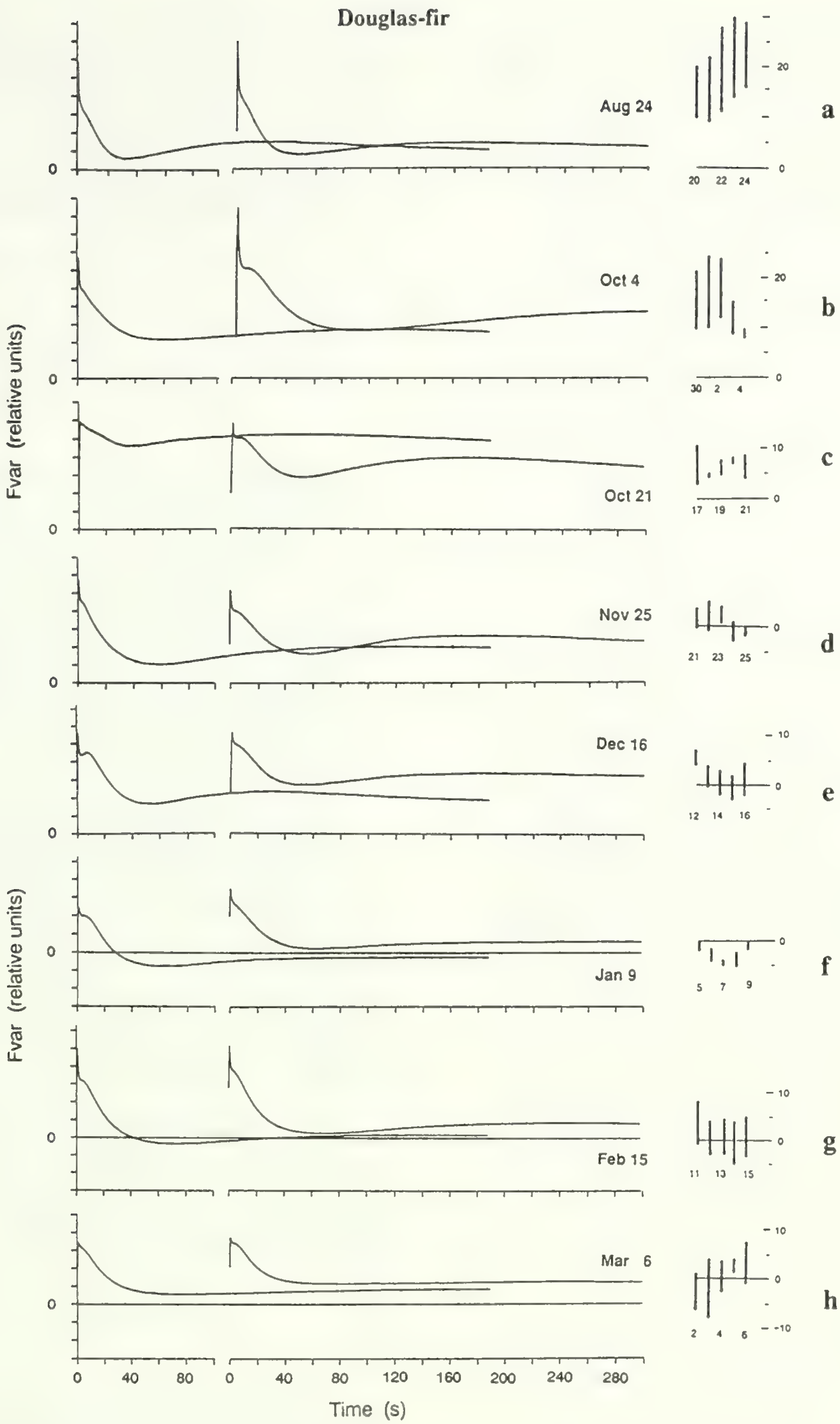

Figure 3(a-h).--F_{var} curves for high elevation (seedlot 6399) and low elevation (seedlot 1273) Douglas-fir seedlings measured over the period from late August 1987 until early March 1988. Responses of 1273 seedlings are shown on the left side of graphs, 6399 on the right. Bar graphs at right display temperature data for four days prior to and on the day of measurement.

Both high (seedlot 6399, 760m) and low elevation (seedlot 1273, 152m) coastal Douglas-fir seedlings displayed indications of water stress in late August when daytime temperatures were approaching 30°C (Fig. 3a). By early October, when temperatures were dropping, seedlings of both provenances showed some recovery in activity but the high elevation seedlings were more active (Fig. 3b). By the third week in October, with further temperature decline, activity decreased in both seedlots but more so in the high elevation seedlings (Fig. 3c). In late November when sub-freeezing temperatures were experienced, activity in both seedlots was low but remained somewhat higher in the low elevation seedlings (Fig. 3d). Activities in both seedlots remained low on Dec. 16 following a period of nighttime frost. The greatest extent of inactivation of both seedlots was observed on Jan. 9 (Fig. 3e), at a time when daily temperatures did not exceed 0°C. Considerable recovery was seen in both seedlots measured on Feb. 15 (Fig. 3g), coinciding with an increase in daytime temperatures. In early March following a period of low temperatures, activities had declined again in both seedlots. These results indicate that photochemical activity in both high and low elevation coastal Douglas-fir seedlings can decline during periods of high or low temperatures. Photochemical activity reached its lowest level during a period when daytime temperatures were below 0°C (Fig. 3f), but higher activity levels were sustained during periods when daytime temperatures were relatively high even though subfreezing temperatures were experienced at night (Fig. 3e, g). These results indicate that inactivation is largely a response to light during low temperature exposure and is in agreement with reports of Strand and Lundmark (1988) and Strand and Oquist (1985). Since activities were relatively high in October when white spruce seedlings would show substantial inactivation (Fig. 1), it appears unlikely that activity in the coastal Douglas-fir seedlings we measured was appreciably affected by daylength. A greater decline in high elevation seedlings during a period of decreasing temperatures (Fig. 3b-c) may indicate that they are more sensitive to chilling than the low elevation seedlings.

Presumably, these response differences relate to ways the species are adapted to their environments (Rehfeldt, 1986). White spruce ranges over a habitat characterized by rigorous winters and the possibility of drought anytime during the growing season. The more severe climate of northern provenances probably accounts for the earlier inactivation of seedlings from such regions. White spruce tends to be a slow growing species but is remarkably resistant to low winter temperatures and summer drought. In part, its slow growth may be attributable to the early fall inactivation of photosynthesis which persists until dormancy is broken in the spring. On the other hand, coastal Douglas-fir is highly opportunistic: it appears to undergo transient inactivation in response to drought or low temperatures but photosynthesis resumes rapidly upon stress alleviation at any time during the year.

It is not yet known whether conifers other than Engelmann (unpublished data) and white spruce possess the daylength-dependent inactivation mechanism. The data presented here suggest it may not be present in coastal Douglas-fir.

OPERATIONAL USES OF F_{var} ASSESSMENT IN THE NURSERY

Variable chlorophyll fluorescence (F_{var}) assessment with an integrating fluorometer is a useful and reliable indicator of photosynthetic activity of intact conifer seedlings. For white spruce, because of the coincidence of photochemical inactivation and the progression toward dormancy, F_{var} data can be used by nursery growers to determine the optimum lifting window dates for this species.

F_{var} assessment also provides information about reactivation of photochemistry. This can be used to monitor seedling recovery from cold dark storage or from the effects of environmental stress. Knowledge of the differences in F_{var} responses can help to optimize nursery operations for the various conifer species and provenance types. Seedling genotypes could be identified using F_{var}, lessening the uncertainity of matching stock types with outplanting site selection.

A commercial version of the integrating fluorometer (Fluoroscan, Intec Inoventures Inc., Victoria, B.C.) is designed to be used operationally by nursery growers. Initial deployment of this system is expected to begin in September 1989.

ACKNOWLEDGEMENTS

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Causes and Control of Overwintering Damage in Nursery Stock[1]

James I. Reid[2]

Abstract.--The process of surviving through the winter in northern climates exacts a visible and invisible toll on tree seedlings. This affects their survival on the nursery, and in the field. The causes for and control of these adverse effects are summarized.

INTRODUCTION

I recently heard the thesis put forward that the "Greenhouse Effect" is in reality a "Ratchet Effect", not so much actively heating up the world's climate as limiting the "fall back" associated with the regular rise and fall of temperatures in the natural long and short term cycles of temperature change. The net effect of this in global terms amounts to heating, but the local effects are more along the lines of increased instability. If this thesis is correct, it means increasing problems for the nurseryman since it is frequently not the severity of conditions which proves to be damaging to stock but the rapidity of change. The prospect is then, if you subscribe to the theories of global climate change, that those nuserymen who have not already experienced damage to their stock will, and those who have, will experience more.

In northern climates winter is a period which can be particularly stessful for plants left in outdoor conditions. For the tree nurseryman the problem is the arrival at the time of shipping with a proportion of the crop in a physiological condition insufficient to ensure successful outplanting. The seedlings which began the overwintering period in apparently acceptable condition but have not survived, have "stressed out". They have succumbed to an accumulation of stresses beyond their resources to deal with. To successfully survive the inevitable stresses of overwintering, the seedlings must begin this difficult period with a minimum of accumulated stress and a maximum of stored reserves. The cultural implications of this are a secondary issue to this study. It must however remain, that our relative success, or lack of it to date, may have been strongly influenced by our ability to come to grips with the requirement to ensure a favourable physiological state.

The Nursery Technology Cooperative of the Oregon State University is currently using what they call "The Target Seedling Concept" as a focus for directed research studies. Simply stated it is:

targeting specific physiological and morphological seedling characteristics that can be quantitatively linked with reforestation success [Oregon State 1988].

It is the milepost at the transfer from nurseryman to field forester which will ensure the greatest likelihood of successful outplanting performance. This implies that the end product of the process of overwintering must not only survive but must possess characteristics assessed to be essential to the seedlings success beyond the nursery gate.

Leaving morphology aside and focusing on the successful plantation tree, what physiological characteristics are required of the seedling as it reaches the end of overwintering? Broadly speaking, stock must still possess sufficient dormancy and cold hardiness to carry it past the risk of

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[1]Paper presented at the meeting of the Intermountain Forest Nursery Association. Bismarck, North Dakota, August 1989.

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frost damage in the field. Its' carbohydrate reserves must not be exhausted, and its' water relations should still be relatively favourable [Ritchie 1986a].

To complete a period of overwintering successfully, it follows that the seedling must begin with root and shoot sufficiently mature and acclimated to withstand the degree and rate of temperature decline which it will experience. It must have adequate carbohydrate reserves to cover losses to respiration during overwintering and have a substantial tolerance for dessication of roots and tops without damage [Ritchie 1984 and 1986b]. Moreover, to fulfill "The Target Seedling Concept" it should be at a sufficiently low level of stress and possess such additional carbohydrate reserves as are needed to successfully establish on a plantation site even under adverse environmental conditions.

THE NEGATIVE IMPACT OF OVERWINTERING

Assuming that we are able to begin overwintering with a "Target Seedling", the critical step is to preserve that seedling until time of planting by providing an environment which protects against excessive demands. Such demands may contribute to a level of "stress accumulation" which results in failure after outplanting. This is difficult to predict and harder to measure. Less frequently the effects of overwintering damage will be more obvious, appearing as physical signs of damage or outright death. These mechanisms are as follows:

Winter Dessication:

Dessication occurs when the rate of transpirational loss exceeds the rate of water uptake. While roots do not become dormant, low temperatures do inhibit activity, reducing the ability of root tips to compensate for rapid transpirational losses by absorbing water. The increasing viscosity of water with falling temperature further reduces the efficiency of water uptake to the point where freezing of the soil water and media halts it altogether. So long as the top is not frozen, the rate of transpiration increases along with increases in light intensity, temperature and wind speed, and in response to decreases in humidity. The disasterous combination of actively transpiring tops and frozen root systems is a condition particularly probable very early and very late in the outdoor overwintering period [Green 1985].

Freeze Damage:

Boreal forest species are among the most cold hardy plants known. Properly conditioned, species such as Jack Pine have been observed to tolerate temperatures as low as -196 degrees Celsius [Green 1985, Dymock 1987]. On the other hand, lush new foliage of these same plants may be severely damaged by any sub-freezing temperature. Frost killing temperature will vary widely depending on the manner of temperature change, the growth stage, the season and the physiological state of the plant. If the plant is inhibited by any of these factors from preventing intracellular freezing, damage will occur.

A major problem in overwintering container grown plants is that the roots are significantly less cold-tolerant than the shoots. This is because while shoot and bud acclimation is dependent on an array of environmental cues, root growth regulation is entirely dependent on temperature. Since roots are never truly dormant, low temperatures (i.e. less than 3 to 5 degrees Celsius) promote hardiness, whereas higher temperatures, at any time, cause deacclimation. Some experts suggest that deacclimation can be complete within 24 hours while full root acclimation may take up to three weeks. As in the case of shoots, freezing conditions during the period when the plant is unable to control intracellular freezing will result in damage [Green 1985, Dymock 1987, Havis 1976, Fuchigami 1982].

Frost Heaving:

Heaving occurs when the soil surface freezes usually during overnight cooling. This frozen layer grips the stems of the seedlings. Soil moisture trapped under this layer then forms ice crystals which lift the surface layer pulling out or tearing the root system . This is particularly a problem in heavier soils.

Frost Cracking:

The bark and outer layers of some species may crack as a result of differential expansion when the exterior thaws or the xylem freezes.

Winter Burn:

The sun can raise foliage temperatures above freezing in winter even when the air temperature is below freezing. At sunset the thawed foliage refreezes rapidly. The rapidity of the freezing causes winter burn [Burke 1978].

Winter Scald:

Winter scald is similar to winter burn but occurs in the bark of the bole.

Frost Smothering:

When saturated media freezes, little or no oxygen can reach tree roots. Since oxygen must be available to support plant metabolism, seedlings may die unless the media thaws and is allowed to release the water occupying the macropore space, normally occupied by air. Damage usually occurs if the situation persists over 48 hours [Burke 1978].

The Key Points

Considering all of the discussed influences likely to adversely affect the state of the crop, the achievement of increased success in overwintering lies in the following key points:

1. Seedlings to be overwintered must be fit. That is, all unnecessary stresses must be minimized, plant reserves maximized, top development and hardening completed and root chilling requirements fulfilled before the plant is subjected to winter conditions.

2. Storage temperature must be, to some degree, controlled. Once freezing has been achieved, it is undesirable for either the root or the shoot to slip into and out of that state and especially not out of syncronization with each other. The rapidity of temperature change may be more critical than the degree.

3. Higher levels of solar radiation should be avoided.

4. Exposure to moving air (over 4 mph) should be minimized.

5. Ambient humidities around the plants should be maximized.

6. Anaerobic conditions in the plant's rooting medium must be avoided.

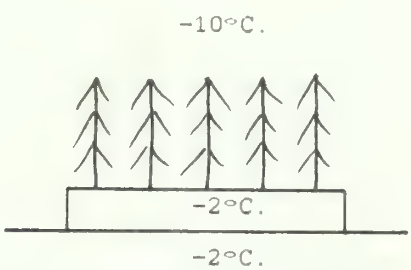
THE PRINCIPLES OF CONTROL

Temperature Control

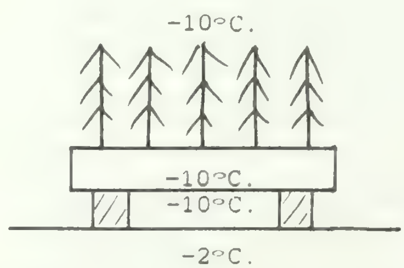
Thermal Mass.--The cheapest and most widely used means of temperature control is thermal mass. This is based on the principle that the greater the mass, the more calories of heat must be exchanged in order to affect a given change in temperature. Since the total amount of stored energy is proportional to the mass, the more mass that is involved the longer it will take to change temperature. In the case of container stock, by placing containers on the ground to create the least possible thermal barrier between the media and the ground we use the thermal mass of the earth to slow the rate of temperature change of the rooting medium.

Thermal Barrier.--Just as we minimize the thermal barrier between containers and the earth, we can also maximize the thermal barrier between any nursery stock and volatile conditions of the environment. This may take the form of a thin mulch barrier placed at the interface of shoot and root, permitting moderation of temperature change in the root and growing media but not the shoot. It can be deeper coverage which envelopes the entire shoot zone or it can be even deeper, resulting in the most extreme temperature conditions occurring well above the shoot zone.

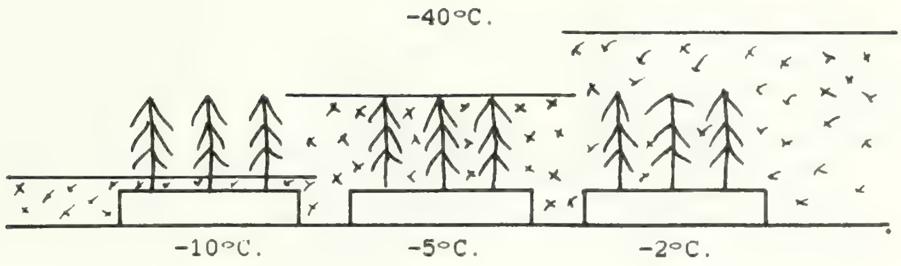
Any material possessing the property of thermal resistivity (R-factor) and inhibiting the exchange of air with the outside environment will insulate the conditions of the stock. The greater the R-factor of the material the slower will be the exchange of heat across it. The less the area of the material, the slower will be the exchange.



Media in trays in contact with the ground will show temperatures near those of the ground.



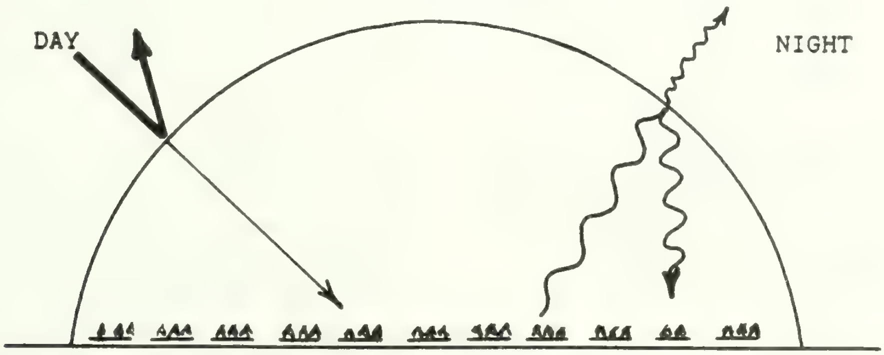
Media in trays not in contact with the ground will show temperatures near those of the air.



Increasing mulch/snow depth increases both the physical amount of the trees protected and the degree of protection afforded. (temperatures are examples only)

Radiant Energy Control.--The regulation of radiated energy by means of a light limiting barrier reduces daytime temperature rise caused by incoming sunshine converted to heat. It may also limit radiated heat loss by reflecting it inward, the overall effect of the two factors being to reduce the range of temperature fluctuation. Snow and mulch covers accomplish this as do most forms of structureless and structured cover.

Environmental Control Systems.--The temperature may be actively controlled by the provision of heating/refrigeration equipment capable of either partially or completely regulating storage temperatures. Provision of such support systems can probably only be practically accomplished within an insulated structure. The cold storage units used in many bareroot operations are good examples of this approach.



Even partial limiting of radiant energy exchange will dramatically moderate temperatures within the cover.

Wind Protection

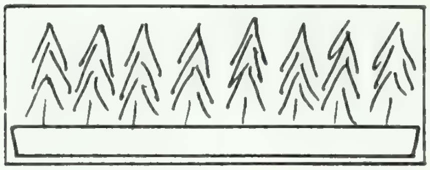
Windbreaks.--The rule of thumb in windbreak management is that the wind shadow effect of a vertical barrier exists for a distance equal to two times the height of the windbreak upwind and five times the height in the lee [Baldwin & Johnston 1985]. Following this assumption, any area encircled by a sufficiently high barrier is, to all intents, completely shielded from wind. If a non-solid material such as shade cloth is employed as the vertical barrier, performance is assumed to be somewhat reduced.

Shade Houses.--Complete enclosure within full walls and overhead cover of shade material may offer an additional increase in protection over walls alone of like material.

Envelopment.--Complete enclosure within an impermeable structure or within structureless covering materials offers complete exclusion of wind. However, free air space within structures may require internal barriers to convective currents.

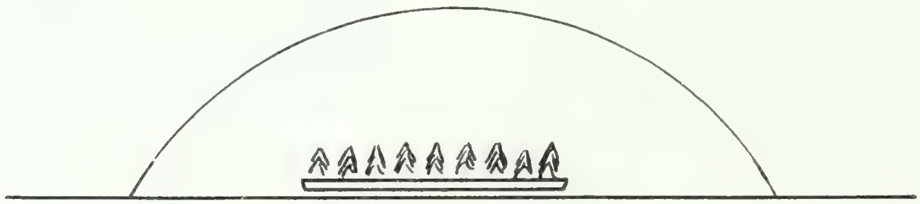
Envelopment may be approached at any level:

-by packaging within closed containers



-by employing structureless covers

-by housing within a closed structure (although some moisture is then shared with the large volume of enclosed air)

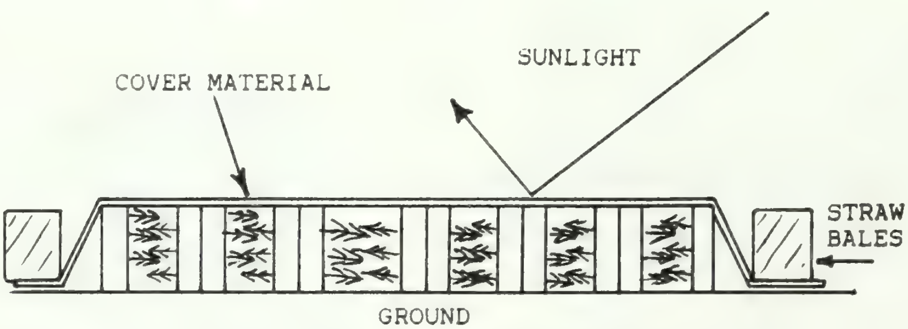


Moisture Control

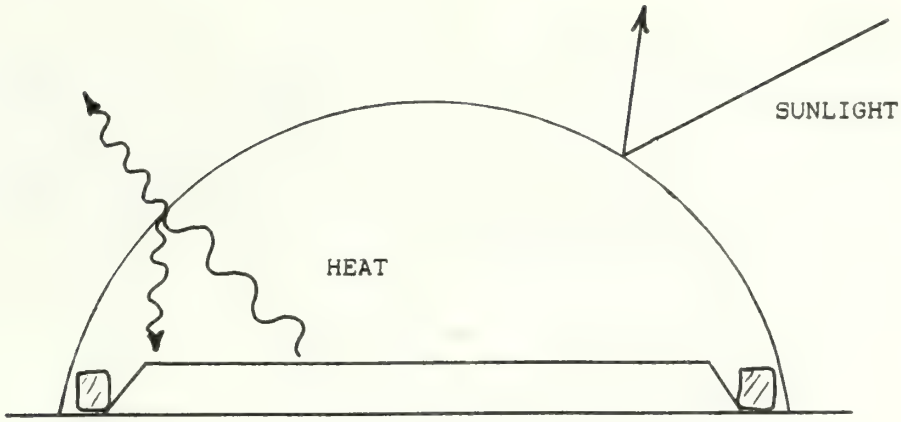
Permeable Cover.--Permeable covers will slow the escape of moisture from the plant environment. This includes fabrics, deep mulches, and snow. Of these, snow is probably the most beneficial. These covers are ineffective in the exclusion of undesirable additional moisture via rainfall.

Envelopment.--Closing the "system" within an impermeable cover retains the inherent plant moisture level. It is additionally effective in excluding unwanted additional moisture in the form of rainfall.

Mechanical Systems.--Mechanical systems designed to introduce humidity may be employed, but are difficult to operate below freezing point. As in the case of other mechanical systems, these are in practical terms best limited to formalized structures.



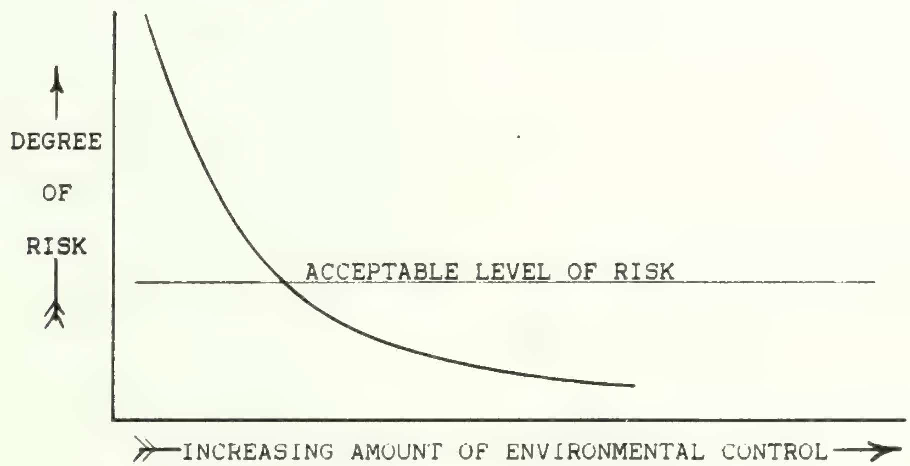
Containers which will stand on their edge facilitate the support of the cover materials. Rodent control can be critical since this is also an attractive overwintering place for such animals.



The use of a structured cover in conjunction with a structureless cover helps to further moderate the overwintering environment.

HOW MUCH CAN YOU AFFORD TO DO?

The bottom line for the nurseryman is not really what he can do but what he can afford to do. It is no surprise that by increasing our expenditure we can increase control and reduce risk. However, instability in weather means increased risk. The question could well become "how much can we afford not to do?"



Present overwintering practices would fall on the curve somewhere above the acceptable level line. Cold storage would be below the line. Placing of other methods requires more trial information.

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White Spruce: The Effect of Long-Term Cold Storage Is Partly Dependent on Outplanting Soil Temperatures[1]

G. Harper, E. L. Camm, C. Chanway, and R. Guy[2]

Seedlings of *Picea glauca* were freezer stored for 0 to 30.5 wks. at -5C, and thereafter grown at three different soil temperatures (3,7,11C). Root growth at 11C increased as seedlings received up to 14 wks. storage duration, and decreased thereafter. In contrast, root growth at the lower temperatures simply decreased with storage duration. Root growth performance and stomatal conductance data both suggest that storage duration greater than 22 wks. can be detrimental to seedling development.

INTRODUCTION

Conifer seedlings for freezer storage, lifted at their peak of cold hardiness and stress resistance, are stored from 4 to 8 months in British Columbia. During this period physiological changes occur which may affect subsequent outplanting vigor and survival. Our area of concern is the effect of storage duration on root growth of seedlings, since limited root growth has been implicated as contributing to failure of large plantations of white spruce (*Picea glauca* (Moench.)Voss.) in B.C. (Butt 1986).

The effect of storage on root growth is not straightforward. In general there is a long decline in root growth capacity with storage, although in Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) there is also a transient increase in root growth capacity after two months storage (Ritchie 1987). This temporary increase is also noted in winter-lifted interior spruce and to a lesser extent in lodgepole pine (*Pinus contorta* Dougl.) (Ritchie, Roden and Klein 1985).

The relationship between storage duration and root growth may be even more complex. Husted and Lavender (1988) tested root growth of white spruce seedlings before and after 6 months storage; there was no net change in root growth in 17C soil, which contrasted with a striking loss in root growth in similar seedlings planted in soil at 3C. The idea that the observed effect of storage duration might depend on the temperature at which seedlings were planted, formed the basis of the present experiment.

An additional factor which seemed relevant in this experiment was the role of stored and newly assimilated carbohydrate. One obvious effect of storage is in the depletion of stored carbohydrates. Carbohydrate depletion has been noted in Douglas-fir (Ritchie 1982), in Ponderosa pine (*Pinus ponderosa* Laws.) (Hellmers 1962), and in Engelmann spruce (*Picea engelmannii* Parry) (Ronco 1973), and poor seedling performance has been attributed to reduced carbohydrate levels (Ritchie 1982, Ronco 1973). However, in some cases, new photosynthate rather than stored carbohydrate appears to be critical for root growth. The development of new roots in Sitka spruce (*Picea sitchensis* (Bong.)Carr.) is partly dependent, and in Douglas-fir, entirely dependent upon the carbohydrate source from the shoots (Philipson 1988, van den Dreissche 1987). Whether new root growth is dependent on carbohydrate reserves or on photosynthate or both, is not understood, but it seemed that the seedling's ability to establish a new root system would be enhanced by an active photosynthetic process. We decided to examine in more detail the root growth of stored white spruce seedlings, at soil temperatures that might be encountered in planting sites, in conjunction with measurements of photosynthetic gas exchange during the first month of growth after storage.

MATERIALS AND METHODS

Container grown white spruce (1+0,PSB 313) obtained from the B.C. Forest Service, were lifted and cold stored at -5C for up to 30.5 wks. (7.5 months). All work was done under normal operational conditions. At approximately one month intervals, seedlings were removed, thawed, potted, and grown for 28 days in three soil temperature treatments (3,7,11C), in a growth chamber at U.B.C. (air temperature 11C, 480 $\mu mol\ m^{-2}s^{-1}$ PPFD, 16 hrs. photoperiod). During this period several gas exchange parameters such as net photosynthesis and stomatal conductance were followed using a Licor 6200 IRGA. Seedlings were measured at 680 $\mu mol\ m^{-2}s^{-1}$ PPFD. New root growth was measured at the end of each growth period.

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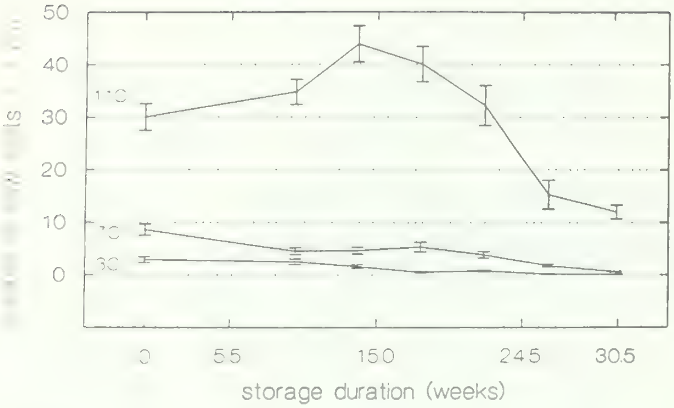

Figure 1 -- New root growth >1 cm. after 28 days at 3,7,11C soil temperatures, and dark freezer storage to 30.5 wks. Error bars are 1 SEM, n=40.

RESULTS

Root growth (as assessed by number of roots longer than 1 cm.) was lower at the colder temperatures (3,7C) than that at 11C over the entire range of storage durations (Fig. 1). In addition, an interaction between soil temperature and length of storage was evident: unstored seedlings (0 wks. storage) planted at 11C produced 3.5 times as many roots as those planted at 7C, although by 30 wks. storage the ratio had increased to 20 times. At this latter storage duration, root production at both temperatures had decreased. An increase in root growth over storage duration was evident only with the high soil temperature, and peaked at 14 wks. In contrast, the colder soil temperatures (3,7C) showed a negative effect on root growth over the entire storage range.

Stomatal conductance and net photosynthesis measurements were not strongly affected by soil temperature (data not shown), although both variables were affected by storage. The data shown in Figures 2 and 3 show similar patterns to those collected from seedlings growth at the other temperatures.

Figure 2 shows the effect of storage duration on stomatal conductance at various periods up to 28 days after outplanting. The first day after outplanting, stomatal conductance was low, and had the same value after all storage durations. However, by day 4 all seedlings showed an increase in conductance which we interpret as stomatal opening. Following this was a general increase in conductance during the rest of the 28 day period after outplanting (shown in Figure 2 as points vertically above each other). This is attributed to increased water loss by developing new foliage after bud break. Storage duration greater than 22 wks. had some effect on this pattern; seedlings stored for the longer periods showed a dramatic increase in conductance after day 1.

Just as with stomatal conductance, changes in net photosynthesis were observed in the 28 day growth period after each storage duration, and this pattern of change was affected by storage duration. With increased storage duration (up to 22 wks), the pattern became more complex, although there was a trend to generally higher levels of net photosynthesis. At longer storage durations, (longer than 22 wks.) the pattern changed; rates of photosynthesis started out low and rose to high levels during the observation period.

Figure 4 shows the effect of storage duration on the number of days from planting to terminal bud break (TBB). This interval was not directly affected by soil temperature, although there was a strong effect of storage duration. Over the entire 30.5 wks. storage period the interval to TBB was found to decrease from about 23 to 8 days (average of three soil temperatures).

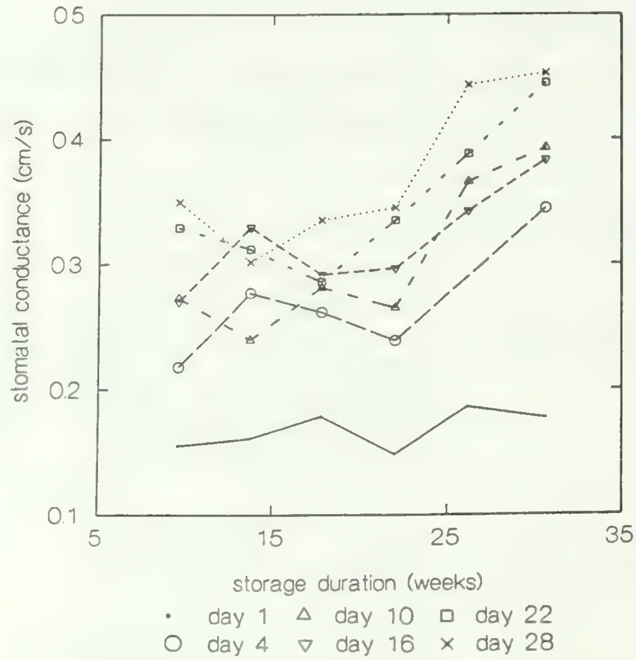

Figure 2 -- Stomatal conductance changes over 28 days growth at 3C soil temperature after varying storage durations, n=40.

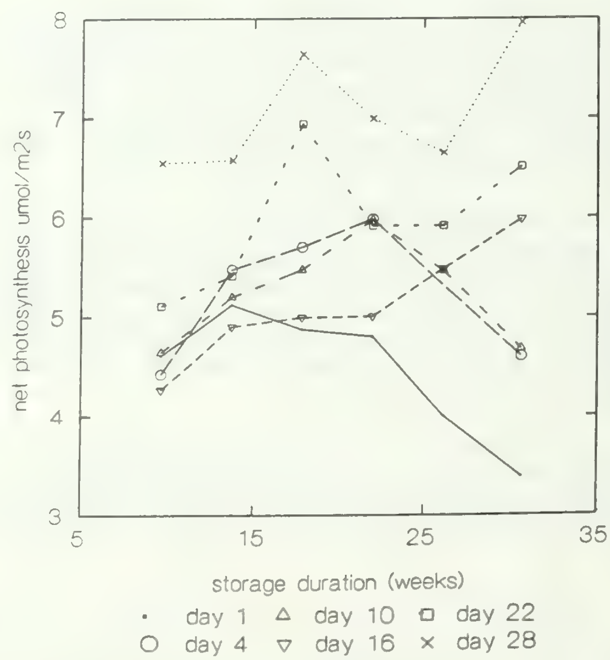

Figure 3 -- Net photosynthesis changes over 28 days growth at 11C soil temperature after varying storage durations, n=40.

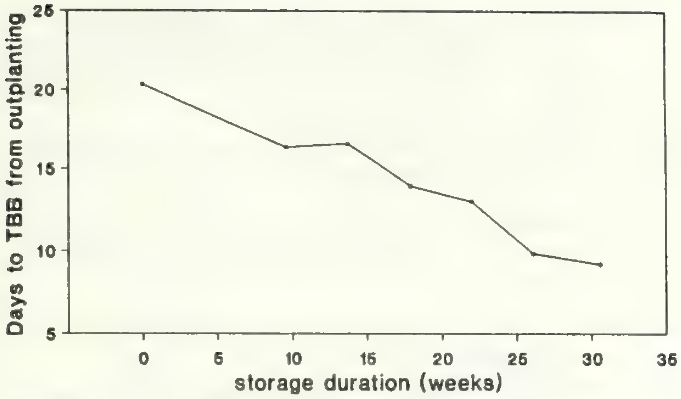

Figure 4 -- Days to terminal bud break (TBB) after varying storage durations, n=120.

DISCUSSION

In this study, we observed relatively little effect of soil temperature on the shoot, as judged by the response of photosynthesis, stomatal conductance and the interval to TBB. This is in direct contrast to the findings of DeLucia (1986), in which root temperatures below 8 degrees caused a strong effect on both photosynthesis and conductance in Engelmann spruce.

However, photosynthesis, conductance and interval to TBB were affected by storage duration. The effect on stomatal conductance was fairly straightforward. After all storage durations, the seedlings demonstrated relatively low stomatal conductance for the first 4 days after planting. We interpret this as part of the seedling recovery process after storage, and it may indicate stomatal opening upon relief of water stress. In the case of seedlings stored longer than 22 wks, we observed that the final stomatal conductance increased with extended storage duration. This general trend may be the result of hormonal activity; abscisic acid (ABA), which has been implicated in stomatal control (reviewed in Zeevaart and Creelman 1988) may decrease with long term storage. Abscisic acid has also been implicated in bud dormancy, suggesting that the increased conductance and shortened interval to terminal bud break (Fig. 4) may be both related to declining ABA levels.

After 22 wks. storage the reduction in net photosynthesis was not correlated with stomatal conductance. This suggests stomatal size was not limiting photosynthesis. After 22 wks. storage, a low photosynthetic rate during the initial 4 days of growth indicates impairment of the photosynthetic system.

In contrast to the shoot parameters, root growth was affected by both temperature and storage duration. With regard to temperature, there are several observations. First, there was much more root growth at 11C than at the lower temperatures. Even at the 11C lowest root growth (30.5 wks.), the number of new roots was 40% higher than the highest observed at the colder temperatures (0 wks.,7C). Second, root growth at 11 degrees showed a transient increase with storage, similar to that discussed in the Introduction. One suggestion to explain this pattern is that chilling is necessary to produce vigorous new roots (peak at 14 wks.) and, as suggested by Zaerr and Lavender (1974), and van den Driessche (1987), root development may be under hormonal control. The fact that this increase was not noted in roots from 3 and 7C soil suggests that the postulated hormonal effect is soil temperature dependent and that a threshold temperature exists for white spruce which is >7C and <11C. Below this threshold soil temperature, storage for any duration had a negative impact on root growth after outplanting. We note that this particular temperature threshold may be provenance or elevation specific.

With regard to the effect of duration, the 22 wks. point again seems important. Root growth at 11C indicates storage durations over 22 wks. severely reduce the seedling's ability to produce new roots. There is a 47% drop in root growth between 22-26 wks.

The decreased interval to TBB is also a factor in reducing root growth, although secondary to the effect of cold soil temperatures. Once bud break occurs, rate of new root development decreases (Mattsson 1981). It is the amount of time photosynthate is available for root growth prior to new foliage development coupled with favorable soil temperature that is important for seedling establishment.

This growth chamber study has shown the complexity of interactions between soil root temperature and storage duration, in relation to carbon fixation, stomatal conductance, and root growth. While this work needs to be followed by field studies, there are some silviculturally relevant implications:

1. Dark freezer storage of white spruce in excess of 22 wks. has a detrimental effect on seedling growth after outplanting. The decline in TBB period and its relationship to root growth has significant implications for nursery practises and planting recommendations.

2. Root growth potential measurements made at relatively warm temperatures may not reflect the actual ability of the seedling to produce roots at lower temperatures.

3. The fact that root growth at low temperatures was adversely affected by all storage durations in this experiment suggests that use of stored seedlings in cold soils may contribute to poor spruce plantation growth.

The key to good establishment depends upon root growth (Mattsson 1981), and as we have seen, root growth depends upon soil temperatures, length of cold storage, and days to TBB. In developing a successful reforestation program careful choice of planting date in consideration with root growth patterns and local planting conditions (soil and light parameters) is necessary to maximize growth potential.

ACKNOWLEDGEMENTS

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Evaluation of *Lonicera* Taxa for Honeysuckle Aphid Susceptibility, Winter Hardiness, and Plant Use[1]

Dale E. Herman and Lawrence J. Chaput[2]

Abstract.--One-hundred honeysuckle taxa were evaluated in North Dakota and/or reviewed in the literature for relative honeysuckle aphid [Hyadaphis tataricae (Aizenberg)] susceptibility, winterhardiness and landscape characteristics. Thirty-nine taxa were rated susceptible or highly susceptible, nine lightly susceptible and 45 with apparent resistance to aphid disfiguration. Only 12 taxa were selected in the very acceptable to highly recommended categories for landscape planting in USDA hardiness zones 2 through 5. Eight taxa were recommended for potential use in shelterbelt or conservation plantings.

INTRODUCTION

The Lonicera genus is a member of the Caprifoliaceae or honeysuckle family. Over 150 species of honeysuckles have been grown in America as well as a large number of cultivars (Bailey and Bailey 1976). Several species have been popular in the Midwest and Northern Plains because of their winterhardiness, adaptation to varied soil and moisture conditions, ease of propagation, and flowering and fruiting characteristics. Although several compact cultivars have been introduced, most species produce medium to large shrubs. Several species have vine-like characteristics. Unfortunately, many species display rather dull leaves by midsummer, lack attractive autumn coloration, and tend to become leggy and unkempt.

Over the past 10 years, the spread of honeysuckle aphid in North America has increasingly devastated many honeysuckles, particularly the species L. tatarica (tatarian honeysuckle), and its' cultivars. Honeysuckle aphid [Hyadaphis tataricae (Aizenberg)] was first reported and described in 1936 in Russia after which it was commonly reported in Europe (Grigorov 1965). Voegtlin (1982) hypothesized that this aphid is native to the area where its host plant, tatarian honeysuckle, is found; i.e., northern and western Asia. The aphid first entered North America in Quebec in the mid-1970's on infested plants from Europe (Boisvert et al. 1981). The earliest observation in the United States was in north-eastern Illinois (Lake County) in 1979 (Voegtlin 1981). Since then, this aphid has spread over a vast area of the Midwest, Great Plains and Canada. Grigorov (1965) gives a detailed account of the insect's biology. Severe witches' brooming is the ultimate effect on susceptible honeysuckle species. Broom-deformed twigs die by fall or in the winter. Damage incurred to susceptible honeysuckles not only results in aesthetic impairment to shrubs in the landscape but sturdy plants may even be killed eventually. Newly planted seedlings or young vigorously growing plants with highly succulent tissues are particularly vulnerable. The damage caused by this insect precipitated a study to re-evaluate the honeysuckle genus for use in landscape and conservation plantings.

[1]Poster paper presented at the Intermountain Forest Nursery Association Annual Meeting [Bismarck, N.D., August 14-17, 1989].
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OBJECTIVES

The objectives of this study were to:

1) Evaluate 100 honeysuckle taxa for susceptibility to honeysuckle aphid.

2) Evaluate honeysuckle taxa with apparent honeysuckle aphid resistance for winterhardiness and landscape characteristics.

3) Provide valid recommendations of honeysuckles for landscape and conservation plantings; particularly in USDA hardiness zones 2 through 5.

4) Initiate a selection program to potentially release one or more superior aphid-resistant cultivars.

METHODS

Sixty-five honeysuckle taxa were grown and evaluated in North Dakota State University (NDSU) research trials. Data on susceptibility to honeysuckle aphid was recorded for three years (1985-87) and data on winterhardiness and landscape characteristics for 5 to 10 years.

Seventy-one honeysuckle taxa were reviewed in the literature to obtain honeysuckle susceptibility ratings. Literature reviewed includes Boisvert et al. (1981), Cummings (1981), Evers[4] (1988), Funk (1982), Lewis (1982), Mainquist et al. (1982), Nielson (1982), Nixon (1983), Pellett et al. (1985a), Pellett et al. (1985b), Sydnor[5] (1988 and Voegtlin (1982). A total of 100 honeysuckle taxa were evaluated and/or reviewed.

Reports in the literature on honeysuckle taxa were invariably ranked for aphid susceptibility or resistance in an arbitrary manner. Definitive point systems or values were not reported. Efforts were made in this study to correlate NDSU evaluations with the literature reviewed by assigning four rating criteria as follows:

1) Highly susceptible - marked leaf and stem distortion, including numerous witches' brooms.

2) Susceptible - leaf and stem distortion visible, including scattered witches' brooms.

3) Lightly susceptible - slight visible distortion of leaves or stems but essentially devoid of witches' brooms.

4) Apparent resistance - no visible distortion of leaves or stems.

Honeysuckle taxa categorized with apparent honeysuckle aphid resistance were evaluated at NDSU and/or reviewed in the literature for winterhardiness zonation and landscape characteristics. Literature reviewed includes Bailey and Bailey (1976), Dirr (1983), Krussman (1977), Rehder (1940), Snyder (1980) and Wyman (1977). The above references were also used to verify scientific nomenclature. In addition, Standardized Plant Names (Kelsey and Dayton 1942) was used to corroborate common names. However, common names are lacking for a considerable number of honeysuckle taxa in the literature.

Primary criteria utilized in evaluating landscape qualities included foliage color, quality and duration; plant height, density and form; and to a lesser degree, flower and fruit characteristics.

Superior F_2 aphid-resistant honeysuckle seedlings are under evaluation from a putative open-pollinated F_1 hybrid. One or more selections may be named and introduced from this pedigree.

RESULTS

Information obtained from this study is summarized in tables 1 through 6. All honeysuckle taxa are listed alphabetically by scientific name. Common names are listed if cited in the literature.

Table 1 lists 39 honeysuckle taxa rated as susceptible or highly susceptible. These two categories are listed together, since both levels of susceptibility preclude recommendation of these taxa for planting.

The species L. tatarica, L. morrowii and L. ruprechtiana are all susceptible to honeysuckle aphid. This is also true for most cultivars and hybrids derived from these species. Seven additional species were also susceptible, including L. maackii var. podocarpa. However, other accessions of the latter species exhibited considerable resistance which is not readily explainable.

Table 2 lists nine honeysuckle taxa which were lightly susceptible to aphid attack. Most of these taxa are questionable in quality and are not commonly planted. L. fragrantissima (winter honeysuckle) has been planted to a limited extent in hardiness zone 5 of the Midwest. Why L. tatarica 'Sibirica' was damaged only lightly is open to question, since most cultivars of this species are highly susceptible.

Table 3 lists 45 honeysuckle taxa which display apparent resistance to honeysuckle aphid injury in NDSU trials and/or review of the literature. L. alpigena, L. caerulea, L. chrysantha, L. ferdinandii, L. maackii and L. xylosteum are all noteworthy examples of species showing resistance. Although L. korolkowii and L. x xylosteoides cultivars displayed resistance in this study, certain authorities question whether these honeysuckle taxa have complete

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[4]Evers, N.P. 1988. Personal Communication, Department of Horticulture, Landscape and Parks, South Dakota State University, Brookings, S.D.

[5]Sydnor, T.D. 1989. Personal Communication, Department of Horticulture, The Ohio State University, Columbus, OH.

Table 1.--Thirty-nine *Lonicera* (honeysuckle) taxa rated as susceptible or highly susceptible to honeysuckle aphid in NDSU evaluations and/or review of the literature.

Scientific Name	Common Name
L. x *amoena*[1]	Gotha H.
L. x *bella*[2]	Belle H.
L. x *bella* 'Albida'	White Belle H.
L. x *bella* 'Atrorosea'	Pink Belle H.
L. x *bella* 'Candida'	Candida Belle H.
L. x *bella* 'Dropmore'	Dropmore H.
L. 'Bouquet'	Bouquet H.
L. *conjugialis*	Purpleflower H.
L. *discolor*	-----
L. *maackii* var. *podocarpa*	Mongolian H.
L. *microphylla*	-----
L. x *minutiflora*[3]	Bunchberry H.
L. *morrowii*	Morrow H.
L. *muendeniensis*[4]	Muenden H.
L. *muendeniensis* var. *xanthocarpa*	-----
L. *muscaviensis*[5]	Muscovy H.
L. x *myrtilloides*[6]	-----
L. x *notha*[7]	Rutarian H.
L. *olgae*	Olga H.
L. *orientalis*	Buckthorn H.
L. *rupicola*	-----
L. *ruprechtiana*	Manchurian H.
L. *tatarica*	Tatarian H.
L. *tatarica* 'Alborosea'	-----
L. *tatarica* 'Angustifolia'	Narrowleaf H.
L. *tatarica* 'Beavormor'	Beavormor H.
L. *tatarica* 'Cardinal'	Cardinal H.
L. *tatarica* 'Carleton'	Carleton H.
L. *tatarica* 'Cheerio'	Cheerio H.
L. *tatarica* 'Grandiflora'	Bride H.
L. *tatarica* 'Hack's Red'	Hack's Red H.
L. *tatarica* 'Morden Orange'	Morden Orange H.
L. *tatarica* 'Mystic Melody'	Mystic Melody H.
L. *tatarica* 'Nana'	Low H.
L. *tatarica* 'Rosea'	Rosy H.
L. *tatarica* 'Valencia'	Valencia H.
L. *tatarica* 'Virginalis'	Maiden H.
L. *tatarica* 'Wheeling'	Wheeling H.
L. *tatarica* 'Zabelii'	Zabel's H.

PARENTAGE OF HYBRIDS:

[1] *L.* x *amoena* (*L.* *korolkowii* x *L.* *tatarica*)
[2] *L.* x *bella* (*L.* *morrowii* x *L.* *tatarica*)
[3] *L.* x *minutiflora* (*L.* *morrowii* x *L.* x *xylosteoides*)
[4] *L.* x *muendeniensis* (*L.* x *bella* x *L.* *ruprechtiana*)
[5] *L.* x *muscaviensis* (*L.* *morrowii* x *L.* *ruprechtiana*)
[6] *L.* x *myrtilloides* (*L.* *angustifolia* x *L.* *myrtillus*?)
[7] *L.* x *notha* (*L.* *ruprechtiana* x *L.* *tatarica*)

Table 2.--Nine Lonicera (honeysuckle) taxa rated as lightly susceptible to honeysuckle aphid in NDSU evaluations and/or review of the literature.

Scientific Name	Common Name
L. demissa	-----
L. fragrantissima	Winter H.
L. insularis	-----
L. insularis x L. tatarica (hyb.)	-----
L. ledebourii	Ledebour H.
L. maximowiczii	Manchurian H.
L. x salicifolia	Willowleaf H.[1]
L. tatarica 'Sibirica'	Red H.
L. tatarinovii	-----

PARENTAGE OF HYBRID:

[1] L. x salicifolia
(L. ruprechtiana x L. x xylosteoides)

Table 3.--Forty-five Lonicera (honeysuckle) taxa with apparent resistance to honeysuckle aphid in NDSU evaluations and/or review of the literature.

Scientific Name	Common Name
L. alpigena	Alps H.
L. alpigena 'Nana'	Dwarf Alps H.
L. x brownii 'Dropmore Scarlet Trumpet'[1]	Dropmore Scarlet Trumpet H.
L. caerulea	Sweetberry H.
L. caerulea var. altaica	Altai H.
L. caerulea var. dependens	-----
L. caerulea (NC-7 Compact selections)	-----
L. caerulea var. edulis	Turkestan H.
L. caerulea 'Kanzu'	Kanzu H.
L. caerulea var. viridifolia	-----
L. chrysantha	Coralline H.
L. chrysantha var. latifolia	Turkestan Coralline H.
L. chrysantha var. villosa	Villous Coralline H.
L. dioica	Limber H.
L. ferdinandii	Ferdinand H.
L. 'Freedom'	Freedom H.
L. glaucescens	Douglas H.
L. x heckrottii[2]	Everblooming H.
L. x heckrottii 'Gold Flame'	Gold Flame H.
L. x heckrottii 'Summer King'	Summer King H.
L. involucrata	Twinberry or Bearberry H.
L. japonica 'Aureo-reticulata'	Yellownet Japanese H.
L. japonica 'Halliana'	Hall's Japanese H.
L. japonica 'Purpurea'	Purple Japanese H.
L. korolkowii	Blueleaf H.
L. korolkowii 'Floribunda'	Broad Blueleaf H.
L. maackii	Amur H.
L. maackii 'Cling Red'	Cling Red H.
L. maackii 'Rem Red'	Rem Red H.
L. maximowiczii var. sachalinensis	Sakhalin H.
L. prolifera	Grape H.
L. sempervirens	Trumpet H.
L. sempervirens 'Magnifica'	Magnifica Trumpet H.
L. spinosa	Thorn H.
L. spinosa var. albertii	Albert H.
L. syringantha	Lilac H.

Table 3.--Forty-five *Lonicera* (honeysuckle) taxa with apparent resistance to honeysuckle aphid in NDSU evaluations and/or review of the literature. (Continued)

Scientific Name	Common Name
L. syringantha 'Grandifolia'	-----
L. tatarica 'Arnold Red'	Arnold Red H.
L. x *tellmanniana*[3]	Tellmann H.
L. vesicaria	-----
L. x *xylosteoides* 'Clavey's Dwarf'[4]	Clavey's Dwarf H.
L. x *xylosteoides* 'Hedge King'	Hedge King H.
L. x *xylosteoides* 'Miniglobe'	Miniglobe H.
L. xylosteum	European Fly H.
L. xylosteum 'Emerald Mound'	Emerald Mound H.

PARENTAGE OF HYBRIDS:

[1] *L.* x *brownii* (*L. hirsuta* x *L. sempervirens*)
[2] *L.* x *heckrottii* (*L.* x *americana* x *L. sempervirens*)
[3] *L.* x *tellmanniana* (*L. sempervirens* x *L. tragophylla*)
[4] *L.* x *xylosteoides* (*L. tatarica* x *L. xylosteum*)

resistance. Additional time may be needed to make a final judgment. It is noteworthy that nearly all of the vine honeysuckle species show resistance. In addition, the apparent resistance of *L. tatarica* 'Arnold Red' is quite important. Based on this study, it is the only tatarian honeysuckle cultivar recommended for general planting since the honeysuckle aphid entered and began to devastate honeysuckles in North America.

Table 4 lists seven taxa which were not categorized in this study due to insufficient and/or conflicting data concerning aphid attack.

Based upon NDSU evaluations and/or review of the literature, table 5 is a summation of honeysuckle taxa with apparent resistance to aphid attack recommended for planting in USDA hardiness zones 2 through 5. Landscape qualities of the species or cultivar, in addition to aphid resistance, determine the category in which the plant appears. Hardiness zones and approximate plant heights are also included.

Only four taxa were highly recommended. Brief descriptive features of these plants are as follows:

L. x *brownii* 'Dropmore Scarlet Trumpet' (Dropmore Scarlet Trumpet H.). A hybrid vine introduced by the late F.L. Skinner, Dropmore, Manitoba with significantly greater winter hardiness compared to other commonly grown vine honeysuckles. It is quite sterile and produces showy orange-scarlet tubular flowers from June to November.

L. maximowiczii var. *sachalinensis* (Sakhalin H.). A large shrub with bright green, attractive foliage and good shrub density.

Table 4. Seven *Lonicera* (honeysuckle) taxa which were not categorized for honeysuckle aphid susceptibility or resistance due to insufficient and/or conflicting data.

Scientific Name	Common Name
L. x *amoena* 'Alba'	White Gotha H.
L. x *amoena* 'Arnoldiana'	Arnold H.
L. nigra	-----
L. obovata	-----
L. tatarica 'Alba'	White H.
L. tatarica 'Des Moines'	Des Moines H.
L. x *xylosteoides*	Vienna H.

Leaves often display a reddish cast on new growth. Purple flowers, dark red fruit. Native to Korea, Japan and Sakhalin Island, USSR.

L. x *xylosteoides* 'Miniglobe' (Miniglobe H.). An introduction from the Morden Research Station, Morden, Manitoba which is superior to 'Clavey's Dwarf' in form, compactness and foliage color. It has a distinct winter hardiness advantage over 'Emerald Mound' in northern zones. It produces creamy colored flowers and very dark red fruits, both somewhat inconspicuous.

L. xylosteum 'Emerald Mound' (Emerald Mound H.). An excellent compact mound-like honeysuckle with emerald-green leaves. Dull creamy-yellow flowers, dark red non-showy fruits. It is not sufficiently winterhardy in northernmost zones. Apparently identical to 'Compacta', originally named in Poland in 1931. The cultivar 'Nana' is also a synonym in the U.S.

The primary reason for not placing 'Arnold Red' and 'Clavey's Dwarf' honeysuckles in the highly recommended category is a general

Table 5.--*Lonicera* (honeysuckle) taxa with apparent resistance to honeysuckle aphid recommended for landscape planting in USDA hardiness zones 2, 3, 4 and 5.

Lonicera taxa	Hardiness zone recommendation	Shrub height (ft.);vine (v)
Highly Recommended		
L. x *brownii* 'Dropmore Scarlet Trumpet' (Dropmore Scarlet Trumpet H.)	2b,3,4,5	v
L. *maximowiczii* var. *sachalinensis* (Sakhalin H.)	3,4,5	6-9
L. x *xylosteoides* 'Miniglobe' (Miniglobe H.)	2,3,4,5	3-4
L. *xylosteum* 'Emerald Mound' (Emerald Mound H.)	4,5	3-5
Very Acceptable		
L. *alpigena* 'Nana' (Dwarf Alps H.)	4b,5	3
L. *caerulea* (NC-7 compact selections of Sweetberry H.)	2,3,4,5	2-4
L. *korolkowii* 'Floribunda' (Broad Blueleaf H.)	3,4,5	6-7
L. *maackii* (Amur H.)	2,3,4,5	9-12
L. *maackii* 'Cling Red' and 'Rem Red' (Cling Red and Rem Red H.)	4b,5	9-12
L. *tatarica* 'Arnold Red' (Arnold Red H.)	2,3,4,5	10
L. x *xylosteoides* 'Clavey's Dwarf' (Clavey's Dwarf H.)	2,3,4,5	6-7
Fairly Acceptable		
L. *caerulea* (Sweetberry H. and its var's. and cv.'s)	2,3,4,5	5-6
L. *dioica* (Limber H.)	2,3,4,5	v (shrubby)
L. *ferdinandii* (Ferdinand H.)	4b,5	8-9
L. *fragrantissima* (Winter H.)	5	6-8
L. 'Freedom' (Freedom H.)	3,4,5	8
L. *glaucescens* (Douglas H.)	2,3,4,5	v (shrubby)
L. *heckrottii* (Everblooming H., including 'Goldflame' and 'Summer King')	4b,5	v
L. *korolkowii* (Blueleaf H.)	4,5	9-10
L. *japonica* cultivars (Japanese H.)	5	v
L. *sempervirens* (Trumpet H., including 'Magnifica')	4,5	v
L. *spinosa* (Thorn H., including var. *albertii*)	3b,4,5	2-3
L. *syringantha* (Lilac H., including 'Grandiflora')	4,5	6
L. x *tellmanniana* (Tellmann H.)	4,5	v
L. x *xylosteoides* 'Hedge King'(Hedge King H.)	3,4,5	5-6
L. *xylosteum* (European Fly H.)	3,4,5	9
Undesirable		
All 39 *Lonicera* taxa in Table 1 which proved susceptible or highly susceptible to honeysuckle aphid, plus the following additional taxa.		
L. *alpigena* (Alps H.)	4,5	8-9
L. *chrysantha* (Coralline H. & var's. *latifolia* & *villosa*)	4,5	8-10
L. *demissa*	3,4,5	10-12
L. *involucrata* (Twinberry or Bearberry H.)	4,5	6
L. *prolifera* (Grape H.)	4,5	v (shrubby)
L. X *salicifolia* (Willowleaf H.)	3,4,5	9

deficiency in foliage quality. 'Arnold Red' also becomes quite tall and leggy. Plants listed in the fairly acceptable category are certainly usable but deficient in one or more landscape qualities. Nearly 50% of the honeysuckle taxa in this study are included in the undesirable category due to aphid susceptibility and/or unsatisfactory landscape qualities.

Table 6 lists eight honeysuckle taxa which are recommended for potential use in shelterbelt, farmstead windbreaks, reclamation and wildlife plantings. All of these are medium-tall to tall in size which may make them more useful for shelterbelt and conservation purposes.

The Lonicera genus has often been relegated to a lower rung on the woody plant generic ladder as far as providing choice landscape plants. Many honeysuckles are characterized by dull foliage, leggy growth habits and a seemingly lifeless appearance in winter. Yet, this genus has provided a very useful group of shrubs due to their winterhardiness and adaptability. Although numerous honeysuckle taxa are very susceptible to honeysuckle aphid, there is still a significant pool of resistant honeysuckles to draw upon in making recommendations. The use of honeysuckles in our landscapes is not a dead issue. Hopefully, as breeding and selection programs progress, the inventory of honeysuckles with landscape merit may be expanded in the future.

CONCLUSIONS

1) Thirty-nine honeysuckle taxa were rated susceptible or highly susceptible, nine lightly susceptible and 45 exhibited apparent resistance to honeysuckle aphid infestation, respectively. Seven taxa were not classified because of insufficient or conflicting data. L. tatarica, L. morrowii and L. ruprechtiana, including cultivars and hybrids derived from these species, were particularly susceptible.

2) All taxa with apparent aphid resistance were evaluated for hardiness zone assignment and landscape qualities. Only four taxa were highly recommended for landscape use, including L. x brownii 'Dropmore Scarlet Trumpet', L. maximowiczii var. sachalinensis, L. x xylosteoides 'Miniglobe' and L. xylosteum 'Emerald Mound'. Eight taxa were rated as very acceptable and 28 taxa as fairly acceptable. All 39 taxa which proved susceptible or highly susceptible to honeysuckle aphid, plus eight additional taxa, were rated as undesirable. These 47 taxa represent nearly 50% of the taxa evaluated in this study.

3) Eight taxa were recommended for potential use in shelterbelt or conservation plantings as replacements for aphid susceptible Lonicera taxa.

4) Selection of apparent aphid resistant superior hybrid seedlings for potential release is proceeding.

Table 6. Eight Lonicera (honeysuckle) taxa recommended for propagation and potential use in shelterbelt or conservation plantings as replacements for aphid susceptible taxa.

Lonicera taxa	Hardiness zone recommendation
L. chrysantha (Coralline H. and botanical varieties)[1]	3,4,5
L. 'Freedom' (Freedom H.)[2]	3,4,5
L. korolkowii (Blueleaf H.)[1]	3b,4,5
L. korolkowii 'Floribunda'(Broad Blueleaf H.)[2]	3b,4,5
L. maackii (Amur H.)[1]	2,3,4,5
L. maximowiczii var. sachalinensis (Sakhalin H.)[1]	3,4,5
L. tatarica 'Arnold Red' (Arnold Red H.)[2]	2,3,4,5
L. xylosteum (European Fly H.)[1]	3,4,5

[1]Since honeysuckle species hybridize freely, there is risk in obtaining true to type honeysuckles if seed is collected from plants growing in close proximity to other species or hybrids.

[2] In order to maintain these cultivars as true clones with apparent resistance to honeysuckle aphid, they must be vegetatively propagated by cuttings, not sexually by seed.

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Summary of Meetings and Contents of Proceedings of the Intermountain Forest Nursery Association: 1960-1989[1]

Marvin D. Strachan[2]

This historical account of 30 years' progress of the Intermountain Nursery Association is included in these 1989 proceedings, and will serve as a Table of Contents for past proceedings. Each of the proceedings is summarized--indicating the host nursery, location, host nurseryman, dates of the annual meetings, and attendance numbers; interesting meeting highlights are also included. The title of each paper, presented together with the author, is listed. The business meeting decisions are also noted.

A complete set of each of the past meeting proceedings are deposited at the library of the U.S.F.S. Rocky Mountain Forest & Range Experiment Station, Fort Collins, Colorado. If more information on a particular paper with any proceedings is desired, you may contact:

Librarian, USDA Forest Service
Rocky Mountain Forest & Range Exp. Station
240 West Prospect
Fort Collins, CO 80526

ANNOTATED RECORD OF MEETINGS

1st Meeting, known as the organizational meeting, was held at the Big Sioux Conifer Nursery at Watertown, South Dakota on August 20, 1960. Marvin Strachan, host nurseryman, presided. Nine nurserymen and support persons attended the meeting, and all presented input pertaining to the need to form a regional nursery association.

Significant actions taken during the meeting were:

1. ORGANIZATIONAL NAME: Intermountain Nurserymen's Association.

2. MEMBERSHIP: Nurseries within the Great Plains and Rocky Mountain region growing or providing seedling trees for conservation and/or reforestation purposes.

3. OBJECTIVES:
   (a) Provide a forum for nurserymen and affiliate personnel to meet and exchange technology, ideas, information, and techniques.

   (b) Exchange equipment and supplies, or information thereof, between states and nurseries, particularly a clearing house of information on surplus and shortages of nursery seedlings.

   (c) Provide research organizations with specific nursery and seedling needs.

   (d) Provide forest nursery needs and accomplishments on a regional basis, particularly coordinated grade stock standards and genetic tree improvement.

4. OFFICERS AND MEETING DATES: Annual meeting to rotate around participating nurseries. Host nurseryman to be in charge of the program, arrangements, dates of the meeting, and preparation of the proceedings. No formal officers or membership dues.

A tour of the nursery and facilities was conducted, and the group agreed to meet at the Bessey Nursery in Nebraska in 1961.

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[1]This information was prepared for the Intermountain Forest Nursery Association meeting, Bismarck, ND, August 14-18, 1989.

[2]Marvin D. Strachan is retired Nursery Manager, Colorado State Forest Service, Ft. Collins, CO and former Nursery Manager and founder of the Big Sioux Nursery, Watertown, SD.

CHRONOLOGY OF PAST MEETINGS ------ INTERMOUNTAIN NURSERY ASSOCIATION

MEETING	HOST NURSERY	LOCATION	NURSERY MANAGER	DATES	ATTENDANCE
1	Big Sioux Conifer	Watertown, SD	Marv Strachan	Aug. 20, 1960	9
2	Bessey	Halsey, NE	Red Meines	Sept. 14-15, 1961	21
3	Monument	Monument, CO	Ed Palpant	Sept. 13-14, 1962	20
4	Montana State	Missoula, MT	Don Baldwin	Sept. 11-13, 1963	28
5	Lucky Peak	Boise, ID	Leroy Sprague	Aug. 19-20, 1964	--
6	Mt. Sopris	Carbondale, CO	Sid Hanks	Sept. 14-16, 1965	40
7	Colorado State	Ft. Collins, CO	John Ellis	Aug. 30-31, 1966	28
8	PFRA- Indian Head	Indian Head, SASK.	Sandy Patterson	Aug. 1-4, 1967	66
9	Green Canyon	Salt Lake City, UT	Clyn Bishop	Aug. 6-8, 1968	21
10	Lincoln-Oakes/Towner	Bismarck/Towner, ND	Lee Hinds/ Jerry Liddle	Aug. 5-7, 1969	31
11	Coeur d'Alene	Coeur d'Alene, ID	Bud Mason	Aug. 4-6, 1970	63
12	Oliver	Edmonton, Alberta	D. Hillson	Aug. 3-5, 1971	54
13	Mike Webster/IFA/ Weyerhaeuser	Olympia, WA	H.Anderson/ R. Eide/J. Bryan	Aug. 8-10, 1972	117
14	Big Sioux Conifer	Watertown, SD	Don Townsend	Aug. 7-9, 1973	35
** The North American Containerized Forest Tree Symposium was held in 1974 instead of the annual meeting.					
15	Montana State	Missoula, MT	Willis Heron	Aug. 5-7, 1975	65
16	Green Timbers/Surry	Richmond, B.C.	Bayne Vance	Aug. 9-12, 1976	120
17	Kansas State	Manhattan, KS	Bill Loucks	Aug. 9-11, 1977	65
18	Humboldt	Eureka, CA	Don Perry	Aug. 7-11, 1978	189
19	Mt. Sopris	Carbondale, CO	John Scholtes	Aug. 13-16, 1979	124
20	Lucky Peak	Boise, ID	Dick Thatcher	Aug. 12-14, 1980	116
21	Oliver/Pine Ridge	Edmonton, Alberta	Ralph Huber	Aug. 11-13, 1981	94
22	J. Herbert Stone	Medford, OR	Frank Morby	Aug. 10-12, 1982	183
23	Nevada State	Las Vegas, NV	Pat Murphy	Aug. 8-11, 1983	78
24	Coeur d'Alene	Coeur d'Alene, ID	Darrell Benson	Aug. 14-16, 1984	190
25	Colorado State	Ft. Collins, CO	Marv Strachan	Aug. 13-15, 1985	83
26	Webster/Mima/IFA	Tumwater, WA	J. Bryan/ K. Curtis/ K. O'Hara	Aug. 12-15, 1986	187
27	Oklahoma State	Oklahoma City, OK	Al Myatt	Aug. 10-14, 1987	80
28	Skimikin	Vernon, B.C.	Ralph Huber	Aug. 8-11, 1988	328
29	Lincoln-Oakes/Towner	Bismarck, ND	Greg Morgenson/ Roy LaFramboise	Aug. 14-17, 1989	77
30	D. L. Phipps	Roseburg, OR	Paul Morgan	Aug. 13-17, 1990	--

The 2nd Meeting of the Intermountain Nurserymen's Association was held at the Bessey Nursery, Nebraska National Forest, Halsey, Nebraska on September 14-15, 1961. Twenty-one people participated. M. K. Meines, host nurseryman, presided as Chairman and introduced Milt Andrews, Timber Management staff, USFS, Denver, who welcomed the group.

AGENDA

Panel discussion topics and the leaders were as follows:
E. Palpant - Monument Nursery - Maintenance of Soil Fertility and the Interpretation of Soil Tests
D. Baldwin - Montana State Nursery - Green Manure Crops
M. Strachan - South Dakota Nursery - Commercial Fertilizers
R. Meines - Bessey Nursery - Soil Fumigants and Fumigation
P. Salisbury - Canadian Forestry, Indian Head - Nematodes
W. Bagley - Univ. of Nebraska - Herbicides for Nursery use
S. Hanks - Bessey Nursery - Mineral Spirits
A. Engstrom - Oklahoma Nursery - Other Chemicals for Nursery Weed Control
S. Hanks/H. Gallaher/J. Ellis - Over Winter Storage of Planting Stock
R. Read - USFS, Lincoln, Nebraska - Nursery Stock Standards - Quality Morphological and Physiological, Caliper, Top Root Balance, Shoot, Height, Age Class and Site Demands on Quality of Stock
P. Salisbury - Canadian Forestry, Indian Head - Insects and Disease Problems and their Control

BUSINESS MEETING

Ed Palpant invited the group to meet at the Monument Nursery at Monument, Colorado in 1962. A tour of the Bessey Nursery was conducted by the host nurseryman.

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The 3rd Meeting of the Intermountain Nurserymen's Association was held at the U.S. Forest Service Monument Nursery, Monument, Colorado on September 13-14, 1962. Twenty people were in attendance for the 2-day meeting. Ed Palpant was the host nurseryman and presided as chairman.

AGENDA

The entire program was structured, so a discussion leader introduced a designated topic, and the participants all assisted with their experience, questions, and knowledge. The discussion leaders and topics were as follows:

J. Nishimura - Soil Scientist, USFS - Soil Texture and Structure Management
M. Strachan - South Dakota Nursery - Plant Growth Response to Various Soil Structure, Texture and Fertility Levels at Various Nurseries
M. Andrews - USFS, Denver - Nursery Administrator - General
E. Priegal - USFS, Denver - Seed Handling Techniques

The discussion topics led to a very good round-table discussion and analysis of the related and some unrelated subjects.

Host nurseryman Ed Palpant and Mr. Harvey Koller, U.S. Air Force Academy, took the group on a field trip to the nearby Air Force Academy to observe the planting reforestation efforts and to view the academy grounds in general. A tour of the Monument Nursery was also accomplished to view the nursery beds, seed extraction, facilities, and experimental hybrid plantings. A banquet was held in the evening at a local restaurant. Don Baldwin invited the group to meet at the Montana State Nursery in Missoula in September 1963.

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The 4th Meeting of the Intermountain Nurserymen's Association was held at the State Forest Nursery in Missoula, Montana on September 11-13, 1963. Don Baldwin, host nurseryman, presided. Twenty eight people registered for this meeting. Gareth Moon, Montana State Forester, welcomed the group. Moon explained that the Montana Nursery had recently been transferred from Montana State University to the Montana State Forestry Department and he was looking forward to seeing the nursery grow and develop to better serve a stepped-up tree planting program.

A structured program with speakers and prepared papers was not planned by the host nursery. Instead, round-table discussion periods were held.

Office Procedures and Records - William Poulsen, Utah, led the discussion period. Each of the participating nurseries stated how tree order forms were handled, tree orders received, and how trees were distributed or delivered to landowners. Each of the nurserymen also described their nurseries, type and amount of production, and the involvement in nursery "paper work"; such as seed records, seeding schedules, investigation reports, treatment plans, seed catalogs, annual stock inventory reports, stock shipment summaries, stock survival records, financial records, and personnel files.

Free-For-All Discussion - Marvin Strachan, South Dakota, led the discussion period. Participants brought up their individual problems, and the answers were fielded and answered by the participating group. Problems discussed were mainly in regard to cold storage, seed stratification, heel-in beds, and weed control.

Two days were spent in touring and visiting the member nurseries in the area. The Montana State Forest Nursery, Missoula - Don Baldwin, Superintendent. Mountain Home Nursery, DeBorgia - Jack Callen, Owner/operation. Savenac Nursery and Seed Extractory, USFS, Haugan - Bud Mason, Superintendent. The new Forest Service Nursery and Seed Extractory at Coeur d'Alene, Idaho, Jim Augenstein, Superintendent was also visited and still under construction.

The business meeting reviewed the progress of the sub-committee on grading stands - Red Meines, Chrm., Ellis (Colorado) and Baldwin (Montana). The committee's recommendations were adopted, but further work was suggested.

Augenstein, a member of the Western Forest Nursery group, announced their 1964 meeting would be held at Lucky Peak Nursery, Boise, Idaho - Leroy Sprague, nurseryman, suggested a joint meeting of the Intermountain and Western Forest Nurserymen. The group agreed to a joint meeting at Boise in 1964.

* * * * *

The 5th Meeting was held at the U.S. Forest Service Lucky Peak Nursery, Boise, Idaho on August 19-20, 1964. The number and names of attendees was not available, but a rather large attendance was on hand. The meeting was chaired by F. Leroy Sprague, host nurseryman. This meeting was the regularly scheduled meeting for the Western Forest Nurserymen. The Intermountain Nurserymen were invited to meet jointly with the Western Forest Nurserymen, and several were in attendance.

TECHNICAL AGENDA - Papers by:

L. Hojem- Production of Larger Douglas-fir seedlings by Fall Sowing
L. Mason- Methods and Time of Sowing
F. Deffenbacher- Sowing Dates and Rates and Their Effect on Production of Stock
H. Ward- New Nursery Equipment and Processes
J. Long- Summary of Progress in the Production of Interior Spruce in British Columbia
J. Christner- New and Better Ways of Packing and Shipping Seedlings
J. Betts- Tree Lifting and Packing Methods at the Bend Nursery
R. Bega- Disease Control in Forest Nurseries
J. Revel- Planting Study of 2-0 Douglas-fir Culls
C. Bigelow- Intensive Soil Management vs. Fumigation in the Control of Weeds
R.J. Boyd- Soil Fumigation Studies at the Cour d'Alene and Savenac Nurseries
H. Anderson- An Economic Study of Weed Control with Four Herbicides in a Forest Nursery
D. Baldwin- Mechanical Means of Weed Control in Forest Nurseries
S. Hanks- The Use of Solvents for Nursery Weed Control
M. Meagher- Growth of Spruce
J. Dick- Report of Committee on Planting Stock Description
J. Trappe/K. Krueger- Seeding Biographies-- Keys to Rational Nursery Practice
C. J. Eden- Use of X-Ray Technique for Determining Sound Seed
L. Baker- Shading and Irrigating

Separate business meetings of the two nursery associations were held. The Intermountain Nurserymen's Association agreed to meet in 1965 at the Mt. Sopris Tree Nursery, Carbondale, Colorado.

The Western Forest Nursery Council agreed to meet in 1966 at Placerville, California. An organizational charter was presented and accepted; selecting the organization name, membership, objective, meeting dates, officers and duties, and terms of office.

* * * * *

The 6th Meeting, forty people attended the meeting at the Mt. Sopris, USFS Nursery near Carbondale, Colorado on September 14, 15, 16, 1965. Chairman for the meeting was Sid Hanks, host nurseryman. Kenneth Scholz, Forest Supervisor, White River National Forest, welcomed the group.

TECHNICAL AGENDA - Papers by:

G. Peterson - Rocky Mt. Forest and Range Experiment Station - Notes on Soil Fumigation in Forest Tree Nurseries
M. K. Meines - Bessey Nursery - Lower Seedbed Densities Can Improve Survival of Pines and Cedars Planted in the Great Plains
R. Read - Rocky Mtn. Forest and Range Experiment Station - Selection of Ponderosa Pine for Plains Planting
J. Ellis - Colorado State Forest Service - Morphological Qualities Contributing to Grade
Marvin Strachan - South Dakota - Physiological Qualities Contributing to Grade
C. Pierce - U.S.F.S. State and Private Forestry - Past Recommendations on Grade by the Grading Standards Subcommittee, Intermountain Nurserymen's Assoc.
S. Hanks - Host Nurseryman - What Constitutes Grade - A Grading Exercise and Panel Discussion

A tour of the Nursery and a Seed Extractory demonstration was held.

BUSINESS MEETING

Since the majority of this meeting centered on grade stock standards, and no conclusive agreement could be attained by the organization on what constitutes grade, it was moved, seconded, and passed that the Subcommittee on Grading Standards be terminated.

Discussion of an annual meeting vs. bienniel meeting. The annual meeting was approved.

Meeting locations and dates were selected as follows:

1966 - Colorado State Forest Service, Fort collins, Colorado.
1967 - Indian Head, Saskatchewan.
1968 - Salt Lake City, Utah.

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The 7th Meeting, twenty eight people attended the meeting in Ft. Collins, Colorado on August 30-31, 1966. Field tours were conducted to the Colorado State Forest Service Nursery, where a potting demonstration and field production fields were inspected. John Ellis, host nurseryman, served as chairman, but since Ellis was preparing to leave the position, he was assisted by the new nursery manager, Marvin Strachan and the field superintendent, Claude Heflin with the tour and arrangements. Tom Borden, State Forester, gave the welcome to Ft. Collins and CSU.

TECHNICAL AGENDA - Papers by:

L. Hinds - Lincoln Oaks Nursery - Nursery Equipment
A. C. Patterson - Indian Head, Saskatchewan - Nursery Equipment
D. Baldwin - Montana State Forest Service - Fertilization
J. Christner - Nevada State Forest Service - Fertilization
D. Tinus - USDA Horticulture - Physiology of Plants
G. Peterson - Problems of a Researcher in the Nursery
E. Heikes - Extension Weed Specialist - Weeding in the Nursery
R. Ulinger - Geneticist, U.S.D.A. - Plant Genetics
M. K. Meines - Bessey Nursery - Winter Storage of Seedlings
S. Hanks - Mt. Sopris - Winter Storage of Seedlings
D. Baldwin/M. Strachan/C. Bishop/M.K. Meines - Growing Methods Used for Spruce, Blue and Engelmann
J. Kepler - Use of Potted Material in Kansas

BUSINESS MEETING

The session was devoted to the availability of surplus trees and setting the 1967 meeting in August at the Indian Head, Saskatchewan Nursery.

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The 8th Meeting of the Intermountain Nurserymen's Association was held at Indian Head, Saskatchewan, Canada on August 1-4, 1967. Sixty-six people registered for the first meeting held outside of the United States. The meeting was chaired by Sandy Patterson, host nurseryman. William Cram, Superintendent PFRA, introduced M. J. Fitzgerald, Director PFRA, who gave the welcome address. A banquet was held in Indian Head, as well as a barbecue at Lake Katepwa Provincial Park. Tours and demonstrations were conducted on the nursery, as well as a tour of the Outlook PFRA Development Farm, the Gardener Dam, and over 1,000 miles of single-row field shelterbelts in Conquest, Sask. area.

TECHNICAL AGENDA - Papers by:

M. Andrews - A Continuous Flow Seed Extractory
L. Mason - Seed Handling
R. Knowles - Seed Viability
L. Carlson - Control of Nursery Diseases
L. Peterson - Control of Injurious Nursery and Shelterbelt Insects
L. Sonmer/D. Benson - Irrigation on the Nursery
J. A. Menzies/R. Tinus - Farm Shelterbelts
R. Ulinger/W. CRAM - Tree Improvement
R. Read/D. Christie/J. Chedzoy - Storage Requirements for Nursery Stock
M. K. Meines - Nursery Programming

BUSINESS MEETING

A letter from Gary Moon, State Forester, Montana was read which urged the Intermountain Nurserymen and the Western Forest Nursery Council to merge into a single nursery association. He pointed out that the Intermountain State Foresters and the Western State Foresters had merged to form the council of Western State Foresters and the nurserymen might want to do likewise.

It was agreed that the 1968 meeting would be in Salt Lake City, Utah, and the 1969 meeting be held in Bismarck, North Dakota.

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The 9th Meeting was held at Salt Lake City, Utah on August 6-8, 1968. Twenty-one people registered. Clyn Bishop, host nurseryman, presided as chairman. 1-1/2 days were spent on technical papers; 1 day on a field trip tour of the Utah State Nursery; and part of 1 day on a business session. Richard Klason, Deputy State Forester, gave the address of welcome and explained how the Utah State Forestry agency operates.

TECHNICAL AGENDA - Papers by:

J. Murphy - Lower Seedbed Densities Can Improve Survival of Conifers
S. Patterson - Conventional Farm Sprinkler System Vs. The Skinner System
B. Ellis - Herbicides for Nursery Use
G. Tyson - Mechanical Weed Control in the Nursery
M. Strachan - Over Winter Storage of Planting Stock
L. Hinds - New and Better Ways of Packing and Shipping Seedlings
L. Sprague - New Equipment and Processes
H. Ward - Maintenance of Soil Fertility
D. Townsend - 2-0 Root Pruned Stock Vs. 2-1 Stock
L. Mason - Shading and Irrigation

BUSINESS MEETING

Bud Mason asked that Coeur d'Alene Nursery be given consideration for the 1970 meeting and explained that the Western Forest Nursery Council would meet there at that time. The group accepted the invitation.

Lee Hinds reminded the group that the meeting in 1969 would be in Bismarck, North Dakota.

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Thirty-one people attended the 10th Annual Meeting in North Dakota on August 5-7, 1969. Lee Hinds, host nurseryman, presided as chairman. The first day of reports and discussion was held at the Theodore Roosevelt National Memorial Park in Medora. The second day was a tour of the Lincoln-Oakes Nursery and SCS Plant Materials Center. The third day consisted of a tour of the North Dakota State Towner Nursery, the Denbigh Dunes Experimental Forest, and the USFS Sheltebelt Laboratory, all near Towner, North Dakota. Of particular interest, in addition to the production processes at Lincoln-Oakes and Towner, was the growth retardants studies at Lincoln-Oakes and the growth increase studies by Dr. R. Tinus at Towner.

TECHNICAL AGENDA

The following nurserymen reported on activities, new developments, production problems, and production shipped-- followed by discussion:

L. Sprague - Boise ID - Lucky Peak Nursery
R. Clark - Milbank, S.D. - Clarkdale Nursery
M. Strachan - Ft. Collins, CO - Colorado State Forest Service
D. Townsend - Watertown, S.D. - Big Sioux Conifer Nursery
H. Ward - Olympia, WA - Mike Webster Forest Nursery
A. C. Patterson - Indian Head, Sask. - PFRA Nursery
C. Bishop - Salt Lake City, UT - Green River Nursery
D. Force - Glenwood Spgs., CO - Mt. Sopris Nursery, USFS.
R. Huber - Winnepeg, Canada - Manitoba Experimental Nursery
W. Heron - Missoula, MT - Montana State Forest Service
J. Chedzoy - Oliver, Alberta - Alberta Provincial Nursery

BUSINESS MEETING

The invitation from J. C. Chedzoy to meet in Alberta in 1971 was accepted. The group will meet in Coeur d'Alene in 1970.

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The 11th Meeting of the Intermountain Nurserymen's Association was held jointly with the Western Forest Nursery Council at Coeur d'Alene, Idaho on August 4-6, 1970. Sixty-three people attended. One day was spent on a field trip tour of the USFS Coeur d'Alene Nursery, and 2 days were devoted to technical presentations. Lee Mason and Steve McDonald served as Co-Chairmen.

TECHNICAL AGENDA - Papers by:

S. Evans - Comments on Changes in Nursery Management in the Northern Region
R. Bingham - Progress in Breeding Blister Rust Resistant Western White Pine
C. Sinclair - Fall Vs. Spring Planting Study
R. Boyd/S. Sinclair - St. Joe National Forest Spring-Fall Planting Study
J. Bryan - Tree Seedling Harvester
R. Shearer - Problems Associated with Western Larch Planting Stock
J. Bryan - Container Planting
E. Hardin - Quick Methods of Determining Viability
R. Boyd - Use of Modern Climatic Data in Nursery and Planting Operations
B. Patee - Freezing of Nursery Stock
R. Ellis - Use of Herbicides
H. Jones - Wilbur Ellis Company
P. Owston - Effect of Storage on Vigor of Douglas-fir Stock
R. Hallman - Mechanized Cone Collection
H. Ward - Soil Fertility
H. Ward - Packaging Large Planting Stock

BUSINESS MEETING

Separate business meetings were held for each of the attending nursery associations.

The Intermountain Nurserymen, chaired by Lee Hinds, North Dakota, spent time and discussion regarding lists of surplus nursery stock. It was recommended that the Division of State and Private Forestry, USFS, to assist and distribute the surplus lists.

It was recommended that the Intermountain Nurserymen meet jointly with the Western Forest Nurserymen in Olympia, Washington in 1972. The 1971 meeting is scheduled to be held at Edmonton, Alberta.

The Western Forest Nurserymen, chaired by Steve McDonald, proposed the consolidation of the two nursery associations, but the plan was tabled and the invitation was extended to meet in 1972 in Olympia.

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The 12th Meeting was held jointly between the Intermountain Nurserymen's Association and the Western Forest Nursery Council in Edmonton, Alberta, Canada on August 3-5, 1971. In spite of airline strikes and schedule interruptions in the United States, 54 persons registered for the second meeting held outside the United States. One day was spent at the Provincial Tree Nursery of the Province of Alberta. An enjoyable picnic lunch was enjoyed, as well as the evening banquet where the honorable Dr. Grant McEwan, Lieutenant Governor, Province of Alberta, spoke to the group and reminded all that the world extends beyond the limits of your own back yard.

TECHNICAL AGENDA - Papers by:

R. C. Hallman - Mechanized Cone Harvesting
A. Radvanyi - Use of R-55 As a Rodent Repellant on Coniferous Seeds
R. W. Tinus - Growing Conifer Seedlings In a Controlled Environment
D. Hillson - The Provincial Tree Nursery; a brief account of its history and function
D. L. Mitchell/ W.C. Kay - Production and Characteristics of Sausage Containers
D. Hocking - Requirements for Successful Seedling Storage
F. W. Deffenbacher - Frost Damage to Nursery Stock, Wind River Nursery
A. C. Patterson - Electronic Seedling Counting
R. Esau - Chemical Weed Control in Tree Nursery Crops
J. W. Edgren - Survival and Growth of Undercut Douglas-fir

BUSINESS MEETING

No official business meeting was called, but the Intermountain Nursery group agreed to meet jointly with the Western Nursery group in Olympia, Washington in 1972.

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The 13th Meeting meeting of the Intermountain Nurserymen's Association met in conjunction with the Western Forest Nursery Council in Olympia, Washington August 8-10, 1972. Hosts for the meeting were the Washington State Department of Natural Resources, the Weyerhaeuser Company, and the Industrial Forestry Association. The proceedings of this meeting were dedicated in honor of Homer S. "Red" Ward, Nurseryman for the Washington State Department of Natural Resources, who passed away in February 1972. The Intermountain Nurserymen will remember "Red" Ward for his attendance at the early meetings of the Intermountain Association and his encouragement, knowledge, and friendship. One hundred and seventeen persons registered for the 3-day meeting. One day was spent in visiting the State operated "Mike" Webster Nursery, the Weyerhaeuser Nursery, and the Industrial Forestry Nursery. An interesting tour of the Olympia brewery was also enjoyed. The welcoming address by Mr. Bert L. Cole, Washington State Commissioner of Public Lands, was followed by an opening address by Mr. D. N. Jeffers, Weyerhaeuser Company, pertaining to some prognostications about the future nursery.

TECHNICAL AGENDA - Papers by:

J. Edgren/C. Bigelow - Sizing Seed Reduces Variability in Sowing Ponderosa Pine
E. Arnold - Effects of Sowing Accuracy on Seedling Size 1-0 and 2-0 Douglas-fir
J. McClellan - Operation and Evaluation of the Stan Hay Drill
P. Owston - Cultural Techniques for Growing Containerized Seedlings
R. H. Hillson - Production of Container Seedlings in Alberta
W. Hite - Controlled Environment Seedling Production
M. Strachan - Production of Container Seedlings in Colorado
R. Holland - Production of Container Seedlings in Washington
E. Van Eerden - Planting and Production of Container Seedlings in British Columbia
W. Hoenke - Growing and Planting Container Stock in Oregon
H. Friese - Tree Seed Certification
J. Isaacson - Stratification Methods and Seed Testing at Coeur d'Alene Nursery
Y. Tanaka - Study of the Pre-Germination Treatment of Douglas-fir Seed in Nursery Use
J. Wheat - Northwest Seed Orchard Status Report
H. Rodger Danielson - Quick-Tests for Determining Viability of Douglas-fir Seed
L. Carlson - Forest Tree Nursery Disease Control
K. Russell - Nursery Soil Disease Assay
J. Zaerr - Lifting Dates and Storage of Douglas-fir Nursery Stock
D. Ray - Seedling Storage and Packing Containers
C. Chaterton - Soil Amendments for Lucky Peak Nursery Soils
S. Hee - Monitoring Soil Fertility at Weyerhaeuser Company's Forest Nurseries
J. Betts - Soil Monitoring at Wind River Nursery
J. Isaacson - Native Shrub Regeneration
D. Lavender - Growth Regulators and How They Effect the Initiation of Dormacy of Nursery Seedlings
H. Jones - Charcoal Row Banding as an Aid to Weed Control in Newly Seeded Forest Nurseries
C. J. Allison - Freeze-Damage Control at the Weyerhaeuser Washington Nursery
F. Deffenbacher - Frost Damage to Nursery Stock
J. Lott - Evaluation of the New Zealand Root Pruner
R. Gray - Grayco Harvester
J. Storms - J. E. Love Seedling Harvester
R. Homes - Sumation and Evaluation 1972 Nurserymen's Meeting

BUSINESS MEETING

The Western Forest Nursery Council and the Intermountain Nurserymen's Association each held separate business meetings. It was agreed that the Intermountain Nurserymen would meet in 1973 at the Big Sioux Conifer Nursery in Watertown, South Dakota in August.

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The 14th Meeting, thirty five people attended the meeting of the Intermountain Nurserymen's Association in Watertown, South Dakota on August 7-9, 1973. Don Townsend, Nursery Manager, presided. Millard Braden, South Dakota State Forester, gave the welcome address. A tour of the Big Sioux Nursery and a catered luncheon at the nursery was enjoyed by all. Tony Dean was a guest speaker at the Wednesday Banquet-"South Dakota of all Places."

TECHNICAL AGENDA - Papers by:

L. Rempel - The Paper Pot System
F. Deffenbacher - Seed Certification in the Northwest
R. Read - Great Plains Tree Improvement
M. Strachan - Green House Production
J. Otta - Seedling Disease Problems
D. Gruber - Chemical Weed Control
All Nursery Representatives - Reports and Discussion - New Developments, Machines, Methods and Problems
G. Naughton - Walnut and Cottonwood Improvement Program
B. Ekblad - Green House
D. Hallman - Survey of Nursery Equipment Needs
J. McConnell - Eastern Tree Seed Laboratory
R. Tinus - Improvements in the Greenhouse Container Process for Raising Tree Seedlings
R. Clark/R. Rulon - Tree Seed Panel

BUSINESS MEETING

The Intermountain Nurserymen agreed to postpone the 1974 official meeting in lieu of the scheduled International meeting of the North American Containerized Forest Tree Symposium in Denver, Colorado. They also agreed to meet at the State Forest Tree Nursery in Missoula, Montana in 1975.

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The 15th Meeting of the Intermountain Nurserymen's Association was held at Missoula, Montana August 5-7, 1975. Sixty five people attended the meeting hosted by the State Forest Tree Nursery, Department of Natural Resources and Conservation. Willis Heron, Nursery Supervisor, was host. Gareth Moon, State Forester, welcomed the group to Montana, and Wayne Hite, U.S. Plywood Corporation, gave the keynote address. The group enjoyed a banquet one evening and tours of the State Forest Tree Nursery in Missoula, U.S. Plywood greenhouse in Bonner, and viewed out-planted seedlings of container and bare root stock in the area.

TECHNICAL AGENDA - Papers by:

E. Salmonson - Future Needs From Intermountain Nurseries
B. Heintz - Shelterbelts
R. Meyn - Mine Reclamation
R. Tinus - Are Bare Root Nurseries Obsolete
L. Mason -
S. Kohler - Insect and Disease in Nurseries
R. Williams - Study of Soil Fungi in Coeur d'Alene Nursery
R. LaRue - Pesticide Laws and Regulations
T. Landis - Mycorrhizae Culturing for Test Nurseries
S. McDonald - Frozen Stock Storage Studies
M. Morton - Genetic Improvement
R. Cunningham - GP-13 Juniperus Study
F. TerBush - Tree Seed Zones
L. Hinds - Seedling Grade
L. Nicholson - Environment
R. Hallman; J. Lott; D. Rising - Equipment Catalog, equipment survey, precision seeder, monitoring greenhouse environment, small seed lots, intensive nursery culture
R. Tinus - Observations and New Information on Greenhouse Container Systems
S. McDonald - Grayco Lifter Modification
G. Naughton - Germination Curves for Kansas Black Walnut

BUSINESS MEETING

The Nurserymen agreed to meet in British Columbia, Canada in 1976 and Kansas in 1977. No further business evolved, but the merits of meeting every other year with the Western Forest Nursery Council was discussed.

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The 16th Meeting was held at Richmond, British Columbia, Canada on August 10-12, 1976. One hundred twenty people registered for the joint meeting of the Intermountain Nurserymen's Association and the Western Forest Nursery Council. The Vancouver airport Hyatt House was the location of the meeting, with Bayne Vance presiding as chairman. Mr. E. L. Young, Chief Forester, British Columbia Forest Service, gave an inspiring welcome address. A banquet was held one evening, and nursery tours were made to Green Timbers Nursery near Whalley; Corbetts Nursery at Aldergrove, and the Surrey Nursery which demonstrated container and bare root production, the paper pot containers, and automated container sowing equipment.

TECHNICAL AGENDA - Papers by

R. Danielson - New Seed Stratification Techniques for Ponderosa Pine and Douglas-fir
J. Lott - Testing of Bareroot Sowing Equipment
J. Arnott - Container Production of High Elevation Species
J. Bryan - Operational Experiences with the Stan Hay Bare-Root Precision Seeder
J. Sutherland - Nematode Control
J. Dangerfield - Mycorrhizae and Conifer Seedling Production

W. Lopushinsky - The Significance of Shoot-Root Ratio for Survival and Growth of Outplanted East-Cascade Douglas-fir and Ponderosa Pine
J. Edgren - Seedbed Density and Recovery of Douglas-fir
D. Lavender/R. Hermann - Effect of Length of Pruned Roots Upon Performance of Douglas-fir Planting Stock
E. VanEerden - Liming of Container Growing Media
S. Slayton - Top Pruning For Size Control
J. Kinghorn - Irrigation of Container Seedlings
P. Hahn - Mechanical Handling and Growing Seedlings in a Quarterblock System
R. Hermann - Herbicide Trials
N. Pelton - Mudpacking
W. Stein - Conifer Seedlings Packaging and Storage
A. Todd - Packaging and Cold Storage Procedures
S. Cowles - Nursery Bedhouse Trials
J. Sweeten/J. Arnott/B. Devitt/E. Van Eerden/W. Revel - Panel Members: The Relationship Between Container and Bareroot Stock Size and Outplanting Survival

BUSINESS MEETING

The Intermountain Nursery group re-confirmed their wishes to meet in Manhattan, Kansas in 1977.

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On August 9-11, 1977, the Intermountain Nurserymen's Association held their 17th Annual Meeting at Manhattan, Kansas. The host was William Loucks, State and Extension Forestry Department of Kansas State University. Sixty-five people were registered. A banquet and field trip were enjoyed, including a tour of the Kansas State Greenhouse and Lath House operations.

TECHNICAL AGENDA - Papers by:

P. Hoekstra - The Washington Scene
S. McDonald - Western Nursery Situation
C. Lantz - Eastern Nursery Situation
R. Read - Tree Improvement in the Great Plains
R. Cunninghan - Certification, Registration, and Release of Tree and Shrub Reproductive Material
E. Belcher/R. Karrfalt - Better Seeds for Nursery Sowing
P. Laird/R. Boyd - Results of Fall Lifting and Overwinter Storage Trials at the Coeur d'Alene Nursery
W. Rietveld/R. Williams - Detection of Dormancy in Black Walnut Seedlings with the Shigometer and an Oscilloscope Technique
J. Riffle - Ecyomycorrhizal Inoculation of Nursery Seedbeds and Container Growing Media
R. Sandquist - Pesticide Regulations as They Effect Nurserymen and Herbicides in the Nursery
H. Thompson - Insecticides for Use in the Nursery
D. Dutton - Uses of Organic Fertilizer at Wind River Nursery
T. Landis - Analysis and Interpretation of Foliage Nutrient Levels in Tree Seedlings
W. Stein - Production and Use of Container Seedlings in the West
R. Tinus - Production of Container Grown Hardwoods
J. McClatchey - Biodegradable Containers
G. Peterson - Fungicides in Tree Nurseries
J. Lott - Progress Report Missoula Equipment Development Center
E. Perry - The Construction and Use of the Humboldt Nursery Tarp Roller
L. Rempel - Mechanization of Saskatchewan Nurseries
J. McCutcheon - Saskatchewan Nursery Operations
B. Elliott - New Developments at Albuquerque Tree Nursery
R. Fewin - A New Windbreak Nursery Facility for Texas
R. Laframboise - Containerized Greenhouse at Towner Nursery
J. Scholtes - Recent Development at Mt. Sopris Tree Nursery
W. Prather - Utah State Nursery Developments and Future Nursery Plans
P. Etheridge - Pine Ridge Forest Nursery Development and Design
E. Perry - Development and Expansion of the Humboldt Nursery
F. Morby - New Developments at Medford Forest Nursery
M. Strachan - Colorado State Forest Service Nursery
D. Miller/R. Schaefer III - Potlatch Begins Container Production at Lewiston, ID
G. Finger - An Introduction to Weyerhaeuser Southern Nursery Operations
M. Frolich - Development of New Production Facility in Southern Nevada
F. Ter Bush - Publication
S. McDonald - Forest Tree Nursery Energy Considerations

BUSINESS MEETING

A short business meeting was held to decide that the 1978 Intermountain Nurserymen's Association meeting would be held in Eureka, California in conjunction with the Western Forest Nursery Council. The 1979 meeting is being planned for the Mt. Sopris, Colorado area.

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The 18th Annual Meeting of the Intermountain Nurserymen's Association was held in conjunction with the Western Forest Nursery Council on August 7-11, 1978 in Eureka, California. Don Perry was chairman and host for the conference, which caused problems as facilities were not planned for the large attendance. A dinner was held at the Samoa Cookhouse, where Stan Schmidt spoke of "The Fabulous Redwood Empire." Simpson Timber Company hosted a California wine tasting experience and a salmon barbecue. The 1-day field trip toured the Clotilde Merlo Forest Nursery, the Humboldt Nursery, and the Simpson Forest Nursery. The keynote address was given by Huey Johnson, California Secretary for Resources.

TECHNICAL AGENDA - Papers by:

F. Morby - An Approach to Fertilization of Bare Root Conifer Seedlings
P. Hahn - Nutrient Requirements of Containerized Nursery Stock
S. McDonald - Irrigation Monitoring in Western Forest Tree Nurseries
J. Lemhouse - Managerial Accounting: Enterprise Cost Accounting for Nurserymen
L. Nickolson - Double or Triple Sorting of Tree Lots
T. Williams - Observation of Coast Redwood Bare Root Seedlings
H. Baer - Redwoods - How to Grow Them in Containers
J. Rydelins - Korbel Forest Nursery: Purpose, Production, Species, and Progress
J. Edgren/M. Greenup/J. Reynolds - An Operational Root Wrenching Trial at Humboldt Nursery
J. Jenkinson/J. Nelson - Seed Source Lifting Windows for Douglas-fir in the Humboldt Nursery
W. Stein - An Integrated Study of Nursery Stock Conditioning Preliminary Observations on Stock Performance
A. Jaramillo - An Integrated Study of Nursery Stock Conditioning: Oscilloscope Readings and Cold Hardiness
C. Cordel/D. Marx - National Pisolithus tinctorius Ecomycorrhizae Nursery Evaluation
M. Srago - The Establishment of Mycorrhazae Using Excised Roots as Inoculum
R. Sandquist - Status of Western Nursery Herbicides Screening Project
R. Stewart/R. Owsten/H. Weatherly - Evaluation of Six Herbicides for Weed Control in Pacific Coast Forest Nurseries
M. Srago - Nursery Disease Problems: Sirococcus Strobilinus
M. Srago - Nursery Disease Problems: Phoma Blight
A. McCain - Nursery Disease Problems: Containerized Nurseries
L. Gillman/R. James - Nursery Disease Problems: Fungicidal Tolerance of Botrytis Cinera
R. Tinus - Shelterbelts for Nurseries
F. Ter Bush - Seedling Production Contract Growing
E. Belcher - Service at the Eastern Tree Seed Laboratory
T. Greathouse - The Importance of Matching Forest Tree Seed Source with Reforestation Site
B. Lowman - Dewinger for Small Seed Lots
J. Campini - Recent Seed Processing Machinery and Techniques
J. Thomas - Principles of Gravity Separation
F. Deneke/T. Landis - The Value of Quality Seed in Forest Tree Nursery Operations and Reforestation Programs
R. Danielson - Methods of Measuring Seed Quality
R. Silen/C. Osterhaus - Reduction of Genetic Base by Sizing of Bulk Douglas-fir Seedlots
R. Tinus - Effect of Parent Tree and Crop Year on Scots Pine Seed Weight
E. Belcher - Aspects of Seed Quality
L. Hinds - Special Processing Techniques of Hardwoods and Shrubs
A. Plummer/K. Jorgensen - Harvesting, Cleaning, and Storing Seed of Western Shrubs
F. Ter Bush - Commercial Services
J. Rydelius/E. Belcher - Cleaning Redwood Seed
S. McDonald - Report to the Intermountain Nurserymen's Association by the Nursery Stock Grading Standards and Nomenclature Committee
S. McDonald - Forest Tree Nursery Soils Testing Program
J. Lott - Overview of the Missoula Equipment Development Center's Current Reforestation Program

BUSINESS MEETING

Steve McDonald submitted his report to the Forest Tree Planting Stock Standards Committee and his report on the nursery soil testing program. The Intermountain Nurserymen were invited to hold their 1979 meeting in the Mt. Sopris Nursery in Colorado.

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The 19th Meeting of the Intermountain Nurserymen's Association met on August 13-16, 1979 at Aspen/Snowmass, Colorado. John Scholtes was the host nurseryman. Attendance was 124. A banquet and luncheon were held at the Snowmass Inn. The field tour for 1 day was held at the Mt. Sopris Federal Nursery, and mine spoil revegetation was observed near Redstone.

TECHNICAL AGENDA - Papers by:

R. Huber - Nursery Scene in Western Canada
C. Lantz - Progress Report: Seedling Production in the South
F. Ter Bush - The Northwest Scene
S. McDonald - The Nursery Situation in the Interior West in 1979
K. Goldsberry - Greenhouse Safety - For Plants and People Alike
R. Ryker - Western Nursery Herbicide Study - 1979 Update
N. Callan - Dacthal Injury on Douglas-fir and True Firs at the Medford Forest Nursery
R. Sandquist - Registration of Herbicides for Use on Forest Nursery Seedbeds
C. Cordell/D. Marx - National Pisolithus tinctorius Ectomycorrhizae Nursery Evaluation Results - 1978
J. Lott - Nursery Equipment Development at Missoula Equipment Development Center
F. Solan/D. Bickelhaupt/A. Leaf - Soil and Plant Analytical Services for Tree Nurseries
S. McDonald - The Soil Testing Program for Tree Nurseries and the Soil Management Workshop
T. Williams - Nursery Management Information System
D. Wermlinger - Contract Pulling
P. Au/T. Hale - Pine Ridge Forest Nursery Container Filling and Seeding Systems
J. Myers - Greenhouse Cropping and Container Washing
B. Elliott - Albuquerque Tree Nursery
F. Morby - Developing a New Nursery
P. Guthrie - Bureau of Indian Affairs Reforestation Policies and Programs
M. Becwar/M. Burke - Low Temperature Extremes: Their Effect on Plants at Timberline
J. O'Brien/J. Fisher - Seed Handling and Large Scale Production of New Mexico Native Junipers
T. Landis - The Saline Soil Syndrome and its Effect on Bare-Root Production in Two Rocky Mountain Area Nurseries
C. Kerr/J. Stehlik/R. Stakes - Trees in the Tundra
G. Walters/H. Horiuchi - Containerized Seedlings: Key to Forestation in Hawaii

BUSINESS MEETING

The Intermountain Nursery group agreed to meet at the Lucky Peak Nursery in Boise, Idaho in 1980.

The Intermountain Nurserymen also expressed interest in attending the North American Forest Tree Nursery Soil Management Workshop to be held in Syracuse, New York in July 1980.

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The 20th Meeting of the Intermountain Nursery Association met in conjunction with the Western Forest Nursery Council on August 12-14, 1980 at the Lucky Peak Nursery in Boise, Idaho. Richard Thatcher, host nurseryman, was chairman of the meeting. One hundred sixteen persons were in attendance. Ralph Peinecke of the Boise Cascade Corporation gave the welcome address, and R. Max Peterson, Chief of USDA Forest Service, addressed the group on present and future trends. A tour of the Lucky Peak Nursery was experienced by the entire group.

TECHNICAL AGENDA - Papers by:

R. Huber - Canadian Nursery Update
R. Tinus - Forestation Concepts and Practices Developing in New Zealand
T. Landis - Report of the North American Forest Soils Workshop
L. Hinds - The American Association of Nurserymen and its Government Nursery Production Committee
R. Ryker - Evaluation of Herbicides for Weed Control in Rocky Mountain- Great Basin Nurseries
D. Edwards - The Western Forest Tree Seed Council
R. Matye - An Introduction to the Westfir Transplant Nursery

C. Cordell/D. Marx - Ectomycorrhizae: Present Status and Practical Application in Forest Tree Nurseries and Field Plantings
S. McDonald/R. Tinus/C. Reid - Root Morphology Control in Forest Tree Seedling Containers
A. Borchert - Quality Cone Collection
A. Elliott - Use of Solar Energy to Dry Cones at the Albuquerque Tree Nursery
D. Altmann/P. Au/L. Lafleur - Production Seed Processing at Pine Ridge Forest Nursery
D. Edwards - A New Prechilling Method for True Fir Seeds
F. Zensen - Seed Processing: Management Techniques
E. Hardin - Quick Test Vs. Standard Germination Test
J. Zaerr/B. Cleary/J. Jenkinson - Scheduling Irrigation to Induce Seedling Dormancy
M. Triebwasser/D. Overhaulser - The Cranberry Girdler in Conifer Nurseries of Western Washington and Oregon
A. Jaramillo - Review of Techniques Used to Evaluate Seedling Quality
J. Hinz - Techniques of Quality Control for Seedling Lifting Operations
D. Dutton - Quality Control: Tree Processing Operation
M. Shearer - Requirements for Quality Irrigation
G. Jacobsen - Field Handling
A. Dahlgreen - Field Handling and Planting
D. Jensen - Mine and Roadside Revegetation in Montana
M. Frolich - IMpact of Desert Forestry on the Plant Materials System of Nevada
T. Williams - Nursery Management Information System

BUSINESS MEETING

The Intermountain Nurserymen agreed to meet in Edmonton, Alberta, Canada in August 1981.

A discussion was held as to the merits of joining the Intermountain Nursery group with the Western Forest Nursery Council. No decision was made.

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The 21st Annual Meeting of the Intermountain Nurserymen's Association was held in Edmonton, Alberta, Canada on August 11-13, 1981. Ralph Huber was host nurseryman and chairman of the Meeting. Ninety four persons registered for the meeting which was marred by the inability of several nurserymen to use air transportation because of strikes in the Untied States. A banquet and luncheons were sponsored by several Canadian companies. A 1-day tour of the Alberta Forest Service Pine Ridge Forest Nursery and the Alberta Tree Nursery (Oliver Nursery) were experienced by the entire group.

TECHNICAL AGENDA - Papers by:

C. Dermott - Reforestation at the Ridge Forest Nursery
H. Oosterhuis - Alberta Tree Nursery and Horticulture Centre
A. Kiil - Reforestation Research in the Prairies: An Overview
S. Wallner/J. Bourque/T. Landis/S. McDonald/R. Tinus - Cold Hardiness Testing of Container Seedlings
R. Tinus - Successful Overwintering of Container-grown Seedlings
H. Spencer - The Painful Problems of Pioneer Propagation Plans and Other Adventures
I. Edwards - Maintaining Soil Fertility in Forest Nurseries in the Prairie Provinces
F. Morby - Irrigation Regimes in a Bare-Root Nursery
T. Landis - Irrigation Water Quality in Tree Nurseries in the Inland West
R. Esau - Herbicide Investigations in Coniferous Tree Nurseries in Saskatchewan and Alberta
G. Brown - Field Vacuum Seeder
B. Polhill - Monitoring Growth Progression Through Root Collar Diameter Measurements
R. Day - Evaluating Root Regeneration Potential of Bare-Root Nursery Stock
A. Wynia - Using Cost Accounting in Nursery Management
R. Bell - IFSCO Cone Handling and Dry Kiln System
R. Schaefer - Cone Handling System From Field to Processor
A. Suhrbier - Avoiding the Nursery-customer war (more aptly, keeping the battles down to only customers you really don't want to deal with anyway)

BUSINESS MEETING

A motion was made for the Intermountain Nurserymen's Association to merge into one single group with the Western Forest Nursery Council. The motion carried. The Western Forest Nursery Council planned to vote on the merger at its 1982 meeting.

The Nursery group agreed to hold their 1982 meeting as a combined meeting in Medford, Oregon. The 1983 meeting was planned for Las Vegas, Nevada.

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The 22nd Meeting was held on August 10-12, 1982. The Intermountain Nurserymen's Association met in a combined meeting with the Western Forest Nursery Council in Medford, Oregon. Frank Morby was the host nurseryman and chairman for the joint meeting. Robert Devlin, Forest Supervisors of the Rogue River National Forest, gave the welcome address. A 1-day tour of the J. Herbert Stone Nursery was experienced by the group. A banquet and luncheons were very successful. One hundred eighty three registered for attendance.

TECHNICAL AGENDA - Papers by:

B. Sery - Small Seedlot Extractory Dorena Tree Improvement Center
M. Hale - Seed Cone Processing at the Bend Pine Nursery
R. Guariglia - True Fir Stratification - A Field Test
R. Tinus - Sand and Hydrogel Seed Covering Improves Germination of Several Hardwoods in Soil That Crusts
D. Hansen - Bedhouse Seedling Production
R. Adams - Irrigation According to PMS and Tensiometer Instruments
R. Eide - Cultural Practices in Growing Western Hemlock and Sitka Seedlings
D. Dutton - Chinese Weeder Geese - Do They or Do They Not Weed in the Nursery
C. Chatterton - Residual Napromide and its Effect on Western Larch at Coeur d'Alene Nursery
C. Youngberg - Soil Testing and Soil Fertility
J. Jenkinson/J. Nelson - 1-0 Douglas-fir: A Bare-Root Planting Option
L. Heidmann - An Initial Determination of the "Lifting Window" for Ponderosa Pine Seedlings Raised at Albuquerque, New Mexico
B. Thompson - Why Fall Fertilize
J. Fischer - Response of Douglas-fir and Ponderosa Pine to Phosphorous Fertilization at the J. Herbert Stone Nursery
J. Laturner - The Belted Seedling Lifter
P. Heide - The Fobro 1500 Forest Nursery Tree Lifter
J. Sedore - Trends in Container Seedling Production
P. Hahn - Containerized Seedling Production in a Shelter House System
R. Schaefer/F. Kidd - Root Egression From Potlatch Corporation Containerized Seedlings
K. Doughton - Transplanting the Douglas-fir Plug
H. Oosterhuis - The Production of Coniferous Transplants Using Spencer Lemaire Containers
J. Lott - Missoula Equipment Development Center - Reforestation Program
D. Lavender/D. McCreary - Effects of Harvest and Packing Technique on Douglas-fir Seedlings
L. Nicholson - The Importance of Good Nursery Quality Control Part 1
C. Hayhurst - The Importance of Good Nursery Quality Control Part 2
K. Seppa - What's New in Herbicides
J. Chandler - Nursery Management Information System
R. Schaefer - Potlatch's Reporting System for Tracking seedling Crops From Requisition to Plantation
R. Thatcher - Contract Grading - Boom or Bust
R. Miller - USDA, Forest Service Nursery Capacity and Stock Needs
S. Schalla - The Capability of Private Nurseries to Meet Federal Long-Term Needs
J. Edgren - Should Private Nurseries Produce Seedlings for Federal Reforestation Programs

BUSINESS MEETING

The meeting was chaired by Frank Morbey, host nurseryman. The subject of combining the Intermountain Nurserymen's Association and the Western Forest Nursery Council was discussed and voted on by the Western Forest Nursery Council membership. A vote was taken and a count of 29 against and 24 for was gathered. The Intermountain Nurserymen voted for merging the two organizations in 1981 at the Edmonton meeting. The two organizations will remain separate at this time. The opportunity to attend the meeting of both groups continues to remain available to all.

The Intermountain Nursery Group will meet in Las Vegas, Nevada in August 1983.

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The 23rd Meeting of the Intermountain Nurserymen's Association was held on August 8-11, 1983 in La Vegas, Nevada. Pat Murphy, Assistant State Forester hosted the meeting. Seventy eight registered for the meeting. Native Plant Materials was the theme for the meeting. Field tours were held at the Nevada State Nursery and Greenhouse.

TECHNICAL AGENDA - Papers by:

J. Young/J. Bundy/R. Evans - Germination of Seeds of Windland Plants
N. Shaw - Producing Bareroot Seedlings of Native Shrubs
T. Landis/E. Simonich - Producing Native Plants as Container Seedlings
S. Monsen - Use of Shrubs on Mine Spoils
D. Nelson - Toward Producing Disease-Free Container-Grown Native Wildland Plants
R. James - Biology and Management of Botrytis Blight
R. Tinus - Salt Tolerance of Ten Deciduous Shrub and Tree Species
J. Sedore - Containerized Seedling Production for Forest Regeneration in the Pacific Northwest
M. Duryea/S. Omi - The Nursery Technology Cooperative: A Coordinated Effort to Improve Seedling Quality
D. McCreary - Using a Pressure Chamber to Detect Damage to Seedlings Accidentally Frozen During Cold Storage
R. Champbell, Jr. - Asexual vs. Sexual Propagation of Quaking Aspen
J. Fisher/G. Fancher - Effects of Soil Amendments on Aspen Seedling Production
H. Khatamian/F. Al-Mana - Growth of Austrian Pine and Norway Spruce Seedlings in Mini-Containers
R. Hallman - Equipment for Revegetating Disturbed Lands
R. Karrfalt/R. Helmuth - Preliminary Trials on Upgrading Platanus Occidentalis with the Helmuth Electrostatic Seed Separator
J. Budy/E. Miller - Survival, Growth, and Root Form of Containerized Jeffrey Pines 10 Years After Outplanting
T. Smith - Growing Containerized Tree Seedlings in a Shadehouse

BUSINESS MEETING

The Intermountain Nurserymen's Association agreed to meet in 1984 in Coeur d'Alene, Idaho in conjunction with the Western Forest Nursery Council. The 1985 meeting was planned for Ft. Collins, Colorado.

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One hundred ninety persons registered for the <u>24th Meeting</u> of the Intermountain Nurserymen's Association meeting in Coeur d'Alene, Idaho August 14-16, 1984. The meeting was held in conjunction with the Western Forest Nursery Council. This was the largest attendance to date for the joint meeting. Darrell Benson, host nurseryman, was chairman for the meeting. Luncheons and a catered dinner on a recreation boat on Coeur d'Alene Lake were enjoyed by all. Field tours were held at the USDA Coeur d'Alene Nursery.

TECHNICAL AGENDA - Papers by:

S. Altsuler - Plug Seedling Success in the High Country
D. Miller/R. Schaefer - Effects of Container Size on White Pine and Douglas-fir Survival and Growth in North Idaho
J. Arnott - Photoperiod Control of Container Seedling
T. Jopson/J. Paul - Influence of Fall Fertilization and Moisture Stress on Growth and Field Performance of Container-Grown Douglas-fir Seedlings
J. Lott - Forest Service Equipment Development Reforestation Program
R. Thatcher - Contract Grading
F. Zensen - Lift and Pack Procedures at the J. Herbert Stone Nursery
R. Darbyshire - Impacts of Nursery Processing on the Survival and Growth of 2+0 Douglas-fir
J. Jenkinson/ J. Nelson - Cold Storage Increases Resistance to Dehydration Stress in Pacific Douglas-fir
S. Cooley - Solarization in Two Pacific Northwest Forest Nurseries
D. Booth - Fluid Drilling for Wildland Plantings: Some Preliminary Studies
R. Huber - New Seeding and Lifting Concepts in British Columbia
M. Hale - Designing the Bend Nursery Tree Inventory System
A. De Haas - The Placerville Nursery Seedling Lifting Bar
R. Langmo/J. Washburn - Seedling Net-Spreading Aid
J. Scholtes - Update on Northeastern Nurseries
P. Au - Pre-emergent Herbicide Trial in White Spruce at Pine Ridge Forest Nursery
J. Doty - Top Mowing at Viewcrest Nurseries
W. Ellington - New Ideas in Fall Planting
B. Thompson/J. Faulconer - Benefits of Knowing Seedling Quality
R. Guariglia/B. Thompson - The Effect of Sowing Depth and Mulch on Germination and 1+0 Growth of Douglas-fir Seedlings
L. Heidmann/S. Haase - Herbicides for Controlling Weeds at the Albuquerque Forest Tree Nursery
P. Malone - Germination of Western White Pine Seed
F. McElroy - Soil Pest Management Programs for Bareroot Nurseries
R. Moreno - Maximum Germinants/Unit of Seed as a Tool for Calculating Bareroot and Container Sowing Calculations

F. Rothe - "Grow and Plant"--Another Way to Do the Job
W. Schroeder - Field Production of Rooted Poplar cuttings for Prairie Plantings
J. Sedore/W. Fangen - Transplant Comparisons at the Webster Nursery Plug-1s and Bareroot 2-1s
W. Sery - Growing Seedlings in Pallet-sized Containers
G. Shrimpton - Four Insect Pests of Conifer Nurseries in British Columbia
W. Stein - Effects of Wrenching Douglas-fir Seedlings in August
N. Vance - Light Reduction and Moisture Stress: Effects on Containerized Western Larch Seedlings
C. Youngberg - Organic Matter-How Much is Enough?

BUSINESS MEETING

The meeting was chaired by Darnell Benson. It was announced that the 1985 meeting of the Intermountain Nurserymen's Association would meeting in Ft. Collins, Colorado in August. The joint meeting of the Intermountain Nurserymen and the Western Forestry Nursery Council will meet in Olympia, Washington in 1986. The Intermountain Nurserymen's Association will be in Oklahoma in 1987.

Tom Landis indicated that a problem exists on how to finance the publication of the proceedings of the nursery conference meetings. A show of hands indicated they would support the printing of proceedings through an additional reasonable fee collected from the membership.

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The 25th Meeting of the Intermountain Nurserymen's Association was held in Ft. Collins, Colorado on August 13-15, 1985. Marvin Strachan, host nurseryman, was meeting chairman. Eighty three people registered for the new concept meeting which featured four concurrent groups to discuss priority topics. Tours included the Colorado State Forest Service Nursery and ecological conditions in Rocky Mountain National Park. A luncheon was held at CSU and a western cookout at Estes Park. Several commercial exhibitors were present.

TECHNICAL AGENDA - Papers by:

S. Dronen - Value of Windbreaks
R. Tinus - In-bed Herbaceous Windbarrier Produced More Ponderosa Pine Seedlings
A. Myatt/M. Vorwerk - Administrative, Economic, and Technical Observations in Developing and Maintaining an Effective Weed Control Program
G. Neill - Nursery Research: A Practical Approach
S. Omi - Soil Compaction: Effects on Seedling Growth
J. Grebasch - Computer Use in Nursery Management
W. Crenshaw - Recent Developments in the Management of Nursery Pests
K. Burr - Greenhouse Production of Quaking Aspen Seedlings
K. Eggleston/R. Sharp - Fertilizer Trials on Containerized Red Pine
R. Danielson - Stratification and Germination of Western White Pine Seeds
J. Hamilton - Development of Underground Cold Storage at Pine Ridge Forest Nursery
J. Barnett/J. Johnson/N. Stumpff - Effects of Ethylene on Development and Field Performances of Loblolly Pine Seedlings

WEED CONTROL PANEL:
L. Alspach - Herbicides for Weed Control in Tree Nurseries
L. Abrahamson - Forest Tree Nursery Herbicide Studies in the Northern Great Plains & Herbicide Phytotoxicity Tables
R. Darbyshire - Herbicides for Conifers: What's New

SEEDLING QUALITY PANEL:
K. Munson - Principals, Procedures, and Availability of Seedling Quality Tests
D. Simpson - When to Measure Seedling Quality in Bareroot Nurseries

C. Johnson - How to Use Seedling Quality Measurements in Container Nurseries

BAREROOT SEEDLING FERTILIZATION PANEL:
T. Landis/J. Fischer - How to Determine Fertilizer Rates and Application Timing in Bareroot Forest Nurseries
R. Selig - Soil Mapping and Testing
I. Edwards - How to Maximize Efficiency of Fertilizers in a Forest Tree Nursery

POSTER PAPER:
K. Burr/S. Wallner/R. Tinus - Cold-Hardiness Testing of Conifer Seedlings

BUSINESS MEETING

The meeting was chaired by Marv Strachan, host nurseryman, following the noon lunch at Lyons Park during the Field trip. It was reconfirmed that the 1986 joint meeting would be held in Olympia, Washington. The Oklahoma delegation stated that plans were proceeding for the Intermountain Nurserymen to meet in Oklahoma in 1987. The Utah delegation offered to host the Intermountain Nursery group in 1989. A motion was made, seconded, and carried by a majority vote to change the name of the Association from "Intermountain Nurserymen's Association" to "Intermountain Nursery Association."

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The 26th Meeting was held on August 12-15, 1986. The Intermountain Nursery Association met in a combined meeting with the Western Forest Nursery Council in Tumwater, Washington. Jim Bryan, Ken Curtis, and Kevin O'Hara were the host nurserymen and chairpersons for the meeting. John McMahon, Weyerhaeuser Company, gave an inspiring opening address. One hundred eighty seven registered for the meeting. Field tours of the I.F.A. Toledo Nursery, the Weyerhaeuser Mima Nursery, and the Washington State Webster Nursery were experienced by the entire group.

TECHNICAL AGENDA - Papers by:

R. Shearer - Western Larch Cones and Seeds - Current Intermountain Research Station Studies
R. Piesch - Tree Improvement Comes of Age in the Pacific Northwest: Implications for the Nurseryman
T. Smith - Stratification Reduced Germination of Ponderosa Pine Seed Collected in New Mexico and Southern Colorado
C. Gansel - Comparison of Seed Stratification Methods for Western White Pine
W. Johnson - Excised Embryo Test for Western White Pine
M. Coleman/J. Dunlap/D. Dutton/C. Bledsoe - Nursery and Field Evaluation of Compost-Grown Coniferous Seedlings
S. Omi/G. Howe/M. Duryea - First-year Field Performance of Douglas-fir Seedlings in Relation to Nursery Characteristics
J. Jenkinson/J. Nelson - Winter Sowing for Production of 1-0 Douglas-fir Planting Stock
E. Olson - Weed Control - Alternatives to Herbicides
S. Steinfield - Seedling Monitoring During the 1-0 Growing Season
T. Smith - Growing Seedlings on a Production Scale in a Shadehouse
G. Ritchie - Some Effects of Cold Storage on Seedling Physiology
S. Hee - Freezer Storage Practices at Weyerhaeuser nurseries
R. Danielson - Seed Laboratory Computerization: A Database for the Forest Tree Seed Industry
V. Wyant - Nursery Crop Management Computer System
D. Bluhm - Using the HP71 Hand-Held Computer for Seedling Inventory
G. Hileman - Root Growth Capacity System
D. Dolata - Root Regeneration Potential
R. Tinus/K. Burr/S. Wallner/R. King - Relation Between Cold Hardiness, Root Growth Capacity, and Bud Dormancy in Three Western Conifers
K. Burr/R. Tinus/S. Waller/R. King - Comparison of Four Cold Hardiness Tests on Three Western Conifers
W. Rietveld - A New, More Efficient Method to Evaluate Root Growth Potential of Planting Stock Using a Root Area Index
R. Laacke/C. Weatherspoon/R. Tinus - Monitoring Cold Hardiness of Tree Seedlings by Infrared Thermography
B. Dunsworth - Root Growth Potential in Coastal Container Species: Trends From Operational Testing and Prediction of Outplanting Performance
P. Hamm/E. Hansen - Stem Canker Disease of Douglas-fir in Nurseries
R. James - Occurrence of Fusarium on Conifer Tree Seed from Northern Rocky Mountain Nurseries
A. Kanaskie - Management of the Top Blight Disease Complex
P. Hamm/E. Hansen - Phytophthora Root Rot in Forest Nurseries of the Pacific Northwest
S. Cooley - Management of Phytophthora Root Rot in Pacific Northwest Conifer Nurseries
G. Shrimpton - Some Insect Pests of Conifer Seedlings in British Columbia
K. Russell - Reducing Fusarium Top Blight in 1-0 Douglas-fir by Irrigation Scheduling
F. McElroy - Options in Controlling Soilborne Peats
F. McElroy - Use of Meta-Sodium and Dazomet Fumigants
Y. Tanaka/K. Russell/R. Linderman - Fumigation Effect on Soilborne Pathogens, Mycorrhizae, and Growth of Douglas-fir Seedlings
D. Overhulser/P. Morgan/R. Miller - Control and Impact of Lygus Damage on 1-0 Douglas-fir Seedlings

BUSINESS MEETING

The 1988 meeting was scheduled for Vernon, British Columbia with Ralph Huber as host. The 1989 meeting of the Intermountain Nursery Association is scheduled for Bismarck, North Dakota. The 1990 joint meeting is scheduled for the Phipps Nursery in Elkton, Oregon.

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On August 10-14, the Intermountain Nursery Association met for the 27th Meeting in Oklahoma City, Oklahoma. ιl Myatt and Clark Fleege were host nurserymen and chairmen for the meeting. The theme was "Meeting the challenge of the nineties." Eighty people registered. A luncheon and cookout were featured, along with a rare treat of rattlesnake handling. Al Engstrom, former nurseryman and retired Oklahoma State Forester, was present and spoke to the group.

TECHNICAL AGENDA - Papers by:

C. Whitcomb - Seedlings, Service, Insights
J. South - Communication as a Design Consideration in Developing a Computerized Nursery Management Environment
W. Rietveld/R. Ryker - Applications of Portable Data Recorders in Nursery Management and Research
R. Erazo - Superabsorbent Hydrogels and Their Benefits in Forestry Applications
J. Mexal/J. Fisher - Organic Matter: Short-Term Benefits and Long-Term Opportunities
R. Oswald - The Trees Unlimited Program: An Experiment in Establishing Seedling Plantings
K. Conway - The Potential of Soil Solarization in Nurseries to Control Soilborne Diseases
K. Fleege - Seedling Production at Oklahoma Forestry Division Forest Regeneration Center
S. Hallgren - Priming Treatments to Improve Pine Seed Vigor
J. Brissette/W. Carlson - Effects of Nursery Density on Shortleaf Pine
W. Carlson/J. Anthony/R. Plyler - Polymeric Nursery Bed Stabilization to Reduce Seed Losses in Forest Nurseries
J. Barnett/J. Brissette - Improving Outplanting Survival of Stored Southern Pine Seedlings by Addition of Benomyl to the Packing Medium
R. Karrfalt - Measuring Tree Seed Moisture Content Now and in the Future
L. Abrahamson - Forest Tree Nursery Herbicide Studies at the Oklahoma Forest Regeneration Center
D. Bickelhaupt - Use of Sulfur to Correct Soil pH
T. Boggus - Certified Vendor Program
W. Rieveld/R. Tinus - Alternative Methods to Evaluate Root Growth Potential and Measure Root Growth
D. Burr/R. Tinus/S. Wallner/R. King - Comparison of Time and Method of Mist Chamber Measurement of Root Growth Potential
S. Hallgren/C. Tauer - Effects of Lift Date, Storage, and Family on Early Survival and Root Growth Potential of Shortleaf Pine
S. Omi/U. Schuch - Fall Lifting: Its Effects on Dormancy Intensity of Ponderosa Pine Seedlings - A Preliminary Investigation
B. Lowman - A Status Report on Nursery and Reforestation Projects at the Missoula Technology and Development Center
G. Kranzler/M. Rigney - Grading Pine Seedlings with Machine Vision
C. Cordell/J. Owen/D. Marx - Mycorrhizae Nursery Management of Improved Seedlings Quality and Field Performance
T. Filer, Jr./C. Cordell - Integrated Pest Management in Forest Nurseries
W. Rietveld/P. Owston/R. Miller - The USFS Reforestation Improvement Program
T. Landis - Government vs. Private Nurseries: The Competition Issue
K. Atkinson - Working Group Sessions on Communications and the Government/ Private Nursery Issue.
Session I: Communications
Session II: Government vs. Private Nurseries

BUSINESS MEETING

The proceedings of this meeting will be published by the Rocky Mountain Forest and Range Experiment Station. The 1988 joint meeting between the Intermountain Nursery Association and the Western Forest Nursery Council will be held in Vernon, British Columbia, Canada. The 1989 meeting of the Intermountain Nurserymen will be held in North Dakota in August.

Marv Strachan has volunteered to prepare historical summary of past nursery proceedings and index them for reference.

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On August 8-11, 1988, the joint meeting of the Intermountain Nursery Association and the Western Forest Nursery Council met at Vernon, British Columbia. This was a very large group in attendance, with three hundred twenty-eight in registration. Ralph Huber, B.C. Forest Service, served as the host nurseryman and chairman for the meeting. Thirty exhibitors showed and demonstrated their products during the conference. A cookout dinner was enjoyed at the local O'Keefe Ranch, together with observation of antique farm and home equipment. A tour of the B.C. Skimikin Nursery near Salmon Arm was experienced by the nurserymen.

TECHNICAL AGENDA - Papers by:

C. Leadem - Dormancy and Vigour of Tree Seeds
R. Bowden-Green - Province of British Columbia Ministry of Forests Seed Centre
J. Maxwell - Macro and Micronutrient Programmes in B.C. Bareroot Nurseries
W. Stein - Nursery Practices, Seedling Sizes, and Field Performance
W. Rietveld - Effect of Paclobutrazol on Conifer Seedling Morphology and Field Performance
D. Simpson - Fixing the Edsel--Can Bareroot Stock Quality be Improved?
G. Hunt - Effect of Controlled-Release Fertilizers on Formation of Mycorrhizae and Growth of Container-Grown Englemann Spruce
D. Wenny - Growth of Chemically Root-Pruned Seedlings in the Greenhouse and the Field
J. Arnott/B. Dunsworth/C. O'Reilly - Effect of Nursery Culture on Morphological and Physiological Development of Western Hemlock Seedlings
C. Hawkins/D. Draper - Height Control of Interior Spruce by Means of Photoperiodic Induction
C. Hawkins/D. Draper/R. Eng - Heating System, Germination Temperature, and Post Germination Fertilizer Regime Effects on White Spruce Nursery Growth
C. Hawkins/B. Hooge - Blackout and Post Planting Bud Phenology in SxS Spruce Seedlings
K. Odlum/S. Colombo - Short Day Exposure to Induce Budset Prolongs Shoot Growth in the Following Year
R. Scagel/G. Davis - Recommendations and Alternative Growing Media for Use in Containerized Nursery Production of Conifers: Some Physical and Chemical Properties of Media and Amendments
I. Armit - The "Izing" of British Columbia Nurseries
M. Pelchat - Managing Nursery Information in the 1980's
U. Wallersteiner - Cumulative Trauma Disorders in Forest Nursery Workers
S. Grossnickle/J. Arnott/J. Major - A Stock Quality Assessment Procedure for Characterizing Nursery-Grown Seedlings
J. Faulconer - Using Forest Hardiness as an Indicator of Seedling Condition
I. Dymock - Monitoring Viability of Overwintering Container Stock in the Prairies--An Overview of a 5-Year Lodgepole Pine Study
T. Landis/S. Skakel - Root Growth Potential as an Indicator of Outplanting Performance: Problems and Perspectives
W. Binder/R. Scagel/G. Krumlik - Root Growth Potential: Facts, Myths, Value
D. Simpson/A. Vyse/C. Thompson - Root Growth Capacity Effects on Field Performance
W. Binder/P. Fielder - The Effects of Elevated Post-Storage Temperatures on the Physiology and Survival of White Spruce Seedlings
W. Vidaver/P. Toivonen/G. Lister/R. Brooke/W. Binder - Variable Chlorophyll Fluorescence and its Potential Use in Tree Seedling Production and Forest Regeneration
K. Burr/R. Tinus - Effect of the Timing of Cold Storage and Cold Hardiness and Root Growth Potential of Douglas-fir
D. Hildebrand/G. Dinkel - Basamid and Solar Heating Effective for Control of Plant-Parasitic Nematodes at Bessey Nursery, NE
R. James/R. Dumroese/D. Wenny - Occurrence and Persistence of Fusarium Within Styroblock and Ray Leach Containers
R. Sturrock/J. Dennis - Styroblock Sanitization: Results of Laboratory Assays From Trials at Several British Columbia Forest Nurseries
R. Dumroese/R. James/D. Wenney/C. Gilligan - Douglas-fir Seed Treatments: Effects on Seed Germination and Seedborne Organisms
L. Husted - Douglas-fir Dieback
S. Campbell - Update on the Environmental Impact Statement for Pest Management at the Federal Nurseries in the Pacific Northwest Region
R. Klapprat - Greenhouse Transplants for Bareroot Stock Production
S. Hee/T. Stevens/D. Walch - Production Aspects of Mini-Plug Transplants
Y. Tanaka/B. Carrier/A. Dobkowski/R. Figueroa/R. Meade - Field Performance of Mini-Plug Transplants
M. Rigney/G. Kranzler - Computer Vision for Grading Tree Seedlings
C. O'Reilly/J. Ownes/J. Arnott/B. Dunsworth - Effects of Nursery Treatment on Shoot Length Components of Western Hemlock Seedlings During the First Year of Field Establishment
C. Sutherland/T. Newsome - Field Performance of Five Interior Spruce Stock Types With and Without Fertilization at Time of Planting
B. Dunsworth - Impact of Lift Date and Storage on Field Performance for Douglas-fir and Western Hemlock
J. Sloan - Auger Hole Shape, Size, and Tree Placement Affect Survival and Root Form of Planted Ponderosa Pine in South Central Idaho
D. Draper/D. Spittlehouse/W. Binder/T. Letchford - Field Measurement of Photosynthetically Active Radiation

BUSINESS MEETING

No official business meeting was held for the Intermountain Nursery Association because of the small number of Intermountain Nurserymen present and the large number of Canadian and Western Forest Nursery Council attendance.

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Minutes of the Annual Business Meeting

The annual business meeting of the Intermountain Forest Nursery Association was called to order at 12:30 P.M. on August 17, 1989 by Ad Hoc chairperson Tom Landis. The first order of business was to discuss the Historical Account of the Association that was developed by Marv Strachan. The group decided that the publication was a valuable record of past meetings and should be included in the Proceedings of this year's meeting. The Proceedings will be published by the USDA Forest Service, Rocky Mountain Station as a General Technical Report; this project will again by funded by Cooperative Forestry.

The next topic was the location of future meetings. Tom announced that the 1990 meeting would be a joint meeting with the Western Forest Nursery Council which would be held in Roseburg, OR on August 13-17, 1990. There was some discussion about the best location for the 1991 meeting and Dave Grierson offered to host the meeting in Salt Lake City, Utah or one of the surrounding ski resort areas. Tom volunteered to work with Dave to organize the meeting.

The treasurer reported that there was some surplus funds left over from the registration fees, and that the monies would be used to sponsor a happy hour later in the day. All remaining funds of the organization will be forwarded to Dave Grierson to help plan the 1991 meeting.

There was no further new business, and so the meeting was adjourned.

List of Attendees

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United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
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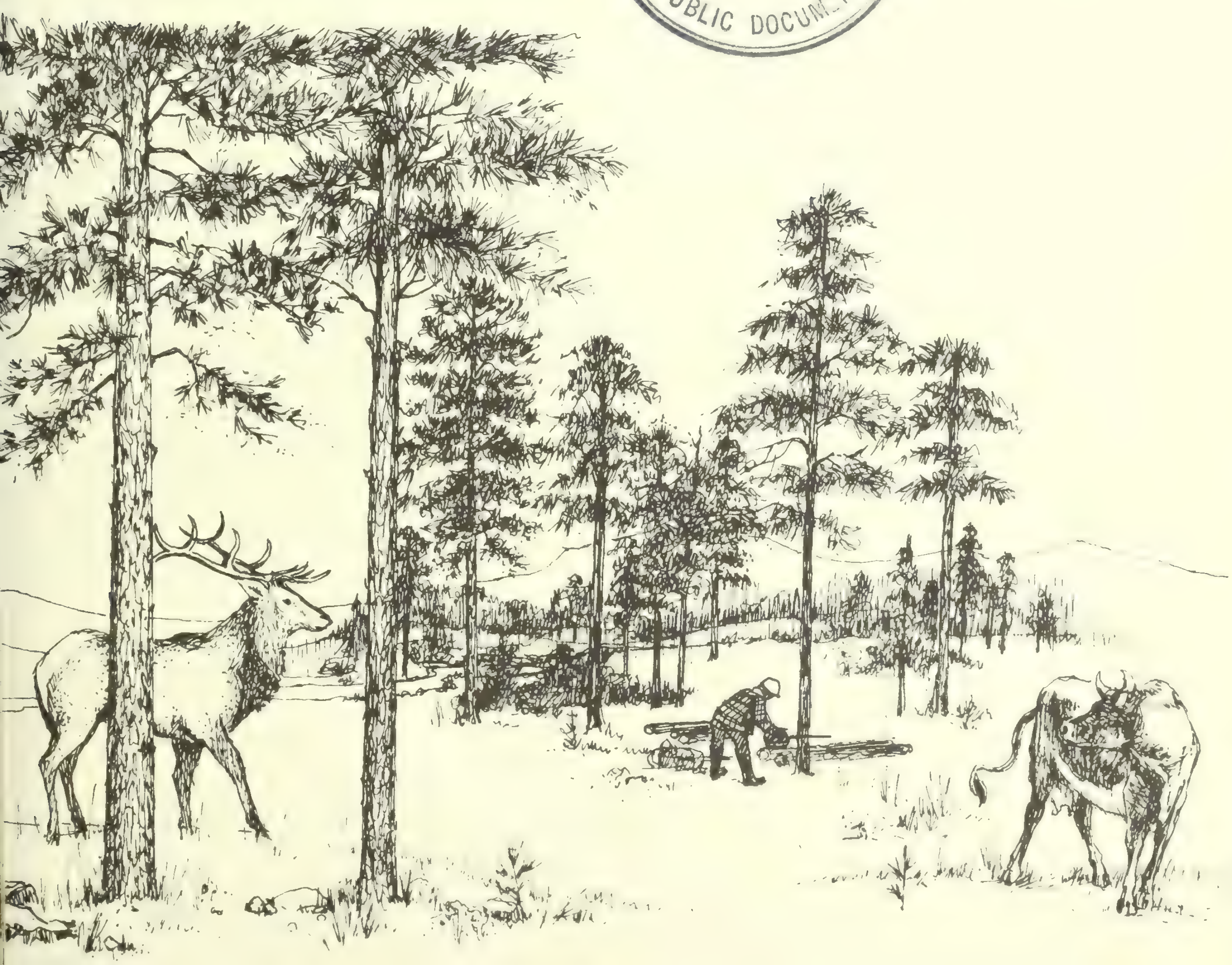
**General Technical
Report RM-185**

Multiresource Management of Ponderosa Pine Forests

Nov. 14 - 16, 1989
Flagstaff, Arizona



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Technical Coordinators:
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Rocky Mountain Forest and Range Experiment Station

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Preface

It is our hope that this conference will be the first in a series of conferences which seek to call together natural resource managers, resource specialists, academicians, agency researchers, and concerned publics to focus on improving integrated ecosystem management of forest lands. For far too long there has been an unhealthy split among many of us. This split stems in part from the fact that each of these groups has a different set of assumptions and goals for management of forest resources. We have witnessed over the past 10 years an increasing propensity of individuals from each of these groups to prejudge individuals of the other groups, discounting what they have to say, simply because they are members of the other group. Isn't this bigotry? Its effect is just as debilitating to natural resource issues as it has been in other human enterprises.

Such a situation is simply no longer affordable. We must develop attitudes of mutual respect and cooperation to bring together the best available knowledge and procedures to generate the optimum management regimes for our public natural resources. Decisions we make today will determine the biological legacy we leave for many generations. We owe it to them and to ourselves to work cooperatively to make the very best decisions that we can, and to document the results of management activities in such a manner that those who follow can learn from our successes as well as from our mistakes. Toward this end, we must learn not only from conventional scientific research, but also from the wealth of knowledge of all of us who are interested in forest land management and from experiential opportunities afforded by whole-system manipulations by managers. Conferences such as this one are a step toward facilitating this learning.

The conference served as a forum for discussing current issues, concerns, opportunities, and procedures in multiresource management of ponderosa pine forests. As such it was able to draw together managers, resource specialists, Forest Service field personnel, representatives of various interest groups, as well as research and development scientists interested in implementing multiresource forest management. The end product of the conference is the publication of these proceedings.

Except for the first two papers – the keynote address and the paper titled *Research Needs in the Southwest Ponderosa Pine Type*, which constitute the conference highlights – the papers in these proceedings are grouped into six themes: (1) areal distribution, and growth of ponderosa pine forests; (2) factors affecting ponderosa pine forest resource outputs; (3) forest diseases, environmental pollutants, and other stresses, (4) wildlife habitat concerns; (5) modeling and integrating environmental and public concerns in ponderosa pine forest resource management, and (6) multiresource management, decision support systems and expert systems. Each of these six parts of the proceedings is preceded by a brief comment by the Session Moderator.

To facilitate rapid publication of the proceedings, the papers were submitted in camera-ready format by the authors. Authors are therefore fully responsible for the accuracy of their papers. The opinions expressed by the authors may not reflect those of the Forest Service, U.S. Department of Agriculture.

W. Wallace Covington
R. H. Hamre
Aregai Tecle

Contents

Beaver Creek and Multiresource Management Forestry[1]

Kel Fox and Lawrence D. Garrett[2]

Abstract.--The emergence of multiresource forest management in the Southwest scientific forestry community is related to the U.S. Forest Service research efforts on the Beaver Creek Experimental Area and later teaching and research efforts at the NAU School of Forestry. A brief history is provided on the evaluation of the Beaver Creek Project and its contribution to multiresource forest management science and practice in the Southwest.

As you can see from the program, Dean Garrett and I are conducting an experiment--giving one talk in two parts. I am leading off, setting the table and providing the hors d'oeuvres. Dave will serve the main course. Together we will be charting some of the history that leads to today's conference on multiresource management.

It begins with the Barr Report, so named for a University of Arizona professor. His directive was to see if the watersheds of the Salt and Verde Rivers were producing as much water as they could and should be producing.

Barr was an agricultural economist by trade, and knew relatively little about the products of the watersheds--trees, water, animals, and so forth. But he knew how to put together a team of experts who could find the answers. He brought men like Hal Wilm to the project. Then dean of the prestigious Syracuse School of Forestry, one of the nation's foremost forestry hydrologists, and a veteran of the first-ever experiment in increasing water yield at Wagon Wheel Gap in Colorado. From the United States Forest Service he signed on Marvin Hoover, who had earned his spurs at Caweeta and Fraser. Dudley Love, who later taught at this university, was included, and so was Bob Humphrey, nationally known for his research on range. And many others of equal ability joined the effort.

The contributions of these experts were refined into a document called "Recovering Rainfall." People soon forgot that catchy title, and referred to it simply as the "Barr Report." The report was optimistic. Yes, more water could be made to flow into the dams so important to the Salt River Valley, including Phoenix. How? By making modifications in existing understory and overstory management direction on the state's watersheds.

For example, clear cut small to medium sized patches in the mixed conifer forest. It will then produce more water, and--get this--more feed for deer and elk, because grass will replace trees in the openings created by the harvest.

To sum up, by reducing tree densities, man could add to his supply of water and the forest could carry more four-legged creatures, both wildlife and livestock.

Here then, was one of the first suggestions of multiresource management. Do something to one resource, in this case timber, and it's going to have an effect on several other resources. That

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[1]Paper presented at the Multiresource Management of Ponderosa Pine Forest Conference, Flagstaff, ARizona, November 14-16, 1989.

[2]Kel Fox is a rancher and technical advisor to the Arizona Lands Commission; Lawrence D. Garrett is Dean of NAU School of Forestry.

is a simplified summation of what multiresource management is all about.

The Barr Report received mixed reviews, some for, some against. But there were enough of us who believed in it to organize an effort to put its theories into practice. That was the genesis of the Arizona Water Resources Committee (AWRC), a group of private citizens formed for the express purpose of persuading the public land management agencies to adopt the report's suggestions.

Before that could be done, however, the agencies, notably the Forest Service, which controled most of the watersheds in the study report, insisted the recommendations be tried under field conditions before putting them in the manual.

The Water Resources Committee eagerly embraced the idea and offered to help obtain the financing to make it a reality. Thus, over the next 20 years AWRC, as it became known, raised more than $10,000,000 for watershed and multiresource management research. At the peak of this effort, there were research projects ongoing in 10 of Arizona's 14 counties.

The centerpiece of this research was a project called "Beaver Creek," located only a few miles from where we are sitting this morning. Though limited to ponderosa pine and pinyon juniper types, Beaver Creek grew so fast it soon overshadowed sometimes older projects examining mixed conifer, chaparral, and phreatophytes.

With a network of good, cinder roads, it was soon playing host to thousands of visitors annually, many of them scientists from foreign countries. To be sure, its emphasis, especially in the early years, was on enhanced water yield. But, from the very beginning, there were studies on what experimental harvests of pine were doing to other resources.

A good example was Watershed No. 9, where the pine was harvested in alternating strips 60 yards wide. Yes, these experiments demonstrated that they could produce more water, but the experiments were directed at a larger question. If these practices were applied to the entire Coconino Forest, what would be the effect on the supply of timber in 1990 or in the year 2,000? And how many additional cows and elk would be supported in the grassed-over strips? What was the effect on fire prevention? And so forth.

Beaver Creek went up like a skyrocket. I feel many great accomplishments came from its programs. Most important, it was one of the ignited fires that has spread to today's concept of multiresource forest management.

For the full story of what it means to the science of multiresource management, we now turn to its last and best-known director: Dr. David Garrett.

Thank you, Kel.

I am David Garrett, and this keynote address is being delivered by Kel and I for two reasons. First and foremost, because the concepts of multiresource forest management in ponderosa pine were not initiated by scientists alone, such as myself, but also by city managers, hunters, and ranchers like Kel Fox.

Second, because Kel is right, Beaver Creek was a significant contributor to multiresource forestry in the Southwest. And, since Kel Fox was instrumental in starting Beaver Creek and I was instrumental in closing it, it seems only fitting that both of us get a chance to revisit it.

Beaver Creek was one of the leading large watershed experiment areas in the 1960's and 1970's, which included Caweeta, Hubbard Brook, and Fraser. However, as Kel mentioned, it had a scientific twist that was different. It attempted to investigate the interactive impacts of tree harvest, grazing, road construction, prescribed fire, etc. on a stream of forest resources; first water yield, sediment, and range, but as it progressed, the resource list grew to include small and large mammals, birds, wildlife habitat, recreation, scenic beauty, tree growth, forest litter, as well as others.

I don't mean to imply that scientific efforts at research watersheds such as Caweeta, Hubbard Brook and others did not focus on the ecosystem and its interaction. They did. However, the mission at Beaver Creek was different, in that it was strongly oriented to addressing forest resource interaction from a multiresource management perspective. Its research was focused toward management application.

The Beaver Creek Watershed Research Area was managed under U.S. Forest Service Rocky Mountain Research Unit 1654, known officially as the "Multiresource Management Evaluation Project" and unofficially as the "Beaver Creek Project." The official title captures the full intent of the research effort.

Led by a Project Director named Harry Brown, the first efforts were to develop individual resource projection models for several resources. These included timber growth, water yield, sediment production, wildlife habitat, forage production, scenic beauty, snow melt, and several others (Brown et al. 1974).

Much of the research that today guides individual resource management in Arizona was derived from university and U.S. Forest Service studies in the Beaver Creek Program. This includes management guidelines for wildlife, recreation, water, range, timber, sediment, prescribed fire, slash disposal, etc.

During the 1970's the Beaver Creek Project attempted to interrelate the impacts of differing resources on one another over time. Interdisciplinary resource specialists designed integrated multiresource sampling procedures and applied them to studies of several resources on a given watershed.

By the late 1970's there was a growing concern nationally that foresters didn't really know the state of the resources on National Forest, BLM, and other federal lands. Further, the general public was suspect that federal lands were not truly being managed well for all forest multiresources. As a result, the 1974 RPA, and the 1976 NFMA and FLPMA mandated multiresource management on all federal forest lands (Wilkinson and Anderson 1987).

Work was beginning on a complex linear programming model, that would later be called FORPLAN and become the central computer model for resolving multiresource planning alternatives at the National Forest level (Jameson et al. 1982). The future of forest management was rapidly becoming focused in legislation, policy and field management activity. The direction would be integrated multiresource forest management.

The scientists at Beaver Creek felt they could respond to the new direction with a method for multiresource analysis; a system model. Systems analysis was not new. Leading scientists, including Lotka and Odum as well as others had stressed the importance of systems science (Lotka 1956, Odum 1983).

However, the effort proposed at Beaver Creek was a forest systems management model. In some ways, the concept was similar to that being advanced by C. S. Holling and his associates at the University of British Columbia, called Adaptive Environmental Management (Holling 1978).

Documenting the extensive data base from Beaver Creek, and development of the forest system management model, ECOSIM, was the last research I and the Beaver Creek scientists completed before closing the infamous project (Rogers et al. 1984).

Today, eight years after closure of Beaver Creek, the focused southwest effort toward multiresource forestry science is at Northern Arizona University. However, NAU's current stature actually results from 15 years of effort.

In 1973, while Beaver Creek efforts were at their peak, NAU School of Forestry launched the first undergraduate forestry program in integrated multiresource forest management in the United States. It was a team taught three semester immersion program; quite progressive for its time.

In 1985, the School launched a special <u>M</u>ulti<u>R</u>esource <u>M</u>anagement (MRM) program at the masters level and in 1986 it launched a mission research program in MRM to support academic efforts.

In 1991 the School expects to have the most comprehensive effort in the United States in MRM, including BS, MS and Ph.D. degree programs, a mission research program, and a specialized Native American program.

Would I say that the Beaver Creek Program was the most influential factor causing NAU School of Forestry to pursue a multiresource forest management emphasis? No, I would not say that. Dr. Minor and the faculty at NAU were watching a national direction in forestry that continues to this day. Beaver Creek, however, was a strong part of that direction in the Southwest.

This week, at this conference, we will focus on accomplishments we have made to better understand the multiresource management of Ponderosa Pine. I applaud the effort by the School of Forestry faculty, the many sponsors, and speakers and attendees. Hopefully, it will be the first of many efforts to follow.

Having involved myself in this special management and science area for a decade now, I feel compelled to comment on two aspects of the endeavor as we begin the conference.

- Why do we need to involve ourselves with multiresource management science?

- Can we expect to effectively implement this direction?

The response to the first question can be found in many professional papers. Writings clearly reveal that this planet is a large ecosystem of interacting physical, biotic, social, economic, political and managerial resources and forces. Since man could reason, great minds have understood this. However, the resource base seemed so immense and so forgiving, that mankind accessed individual resources with limited regard for impacts to others.

Today, in forestry and natural resources, laws and social pressure demand that we incorporate a comprehensive understanding of all impacts from a management action, before the action is implemented. Although I sympathize with many regarding process weaknesses in the National Forest Management Act and other legislation that mandates this direction, I am convinced that on the whole, these laws embody the appropriate direction for proper resource management.

Issues such as global warming and the greenhouse effect best characterize the necessity to approach forest management from a complete holistic system concept. Ignoring physical, biotic, political, social, economic or management aspects of the problem will result in, at best, partial solutions.

And, our second question, can we expect to effectively implement this direction.

Educational, scientific, and management writings also document that comprehensive system approaches are possible. They are also difficult, expensive, not easily understood, and therefore meet with a lot of resistance.

Yet, integration of forestry teaching methods, curriculum and disciplines have been accomplished at least partially in several forestry schools. At NAU we have found we can effectively integrate our entire curriculum. More schools are increasing their efforts to integrate parts of their curriculums.

Integration of system concepts in forest research seems more easily incorporated into current institutions. However, difficulties do exist. For example; university research normally rewards individual accomplishment, and, in fact, success often results from being a specialist in a very narrow field.

In federal and state agencies, both funding mechanisms and administrative direction create difficulties with integrated multiresource research approaches. Projects are generally organized and funded along single resource lines, are often administratively and physically separate, and generally report to differing line and staff managers.

As a result, only a handful of research projects with a multiresource management mission were ever created within the United States Forest Service. In academics, a few programs have also been developed, mostly as a result of large outside contracts. However, a multiresource forest research program developed as a school's central mission, with state funds, such as at NAU, is rare.

In the area of management, the U.S. Forest Service "Integrated Resource Management Program" (IRM) is still the most successful on the ground application of this philosophy (Jameson et al. 1982). The USFS is organized in a manner that permits rapid implementation. That is, both the budget process and management process support the direction. Although budgets are allocated by resource area, all resource areas and budgets are under control of the district ranger. Further, the ranger also controls an interdisciplinary group of specialists to implement IRM.

A final note. Although good approaches to MRM exist in teaching,

research and management, and are growing in numbers, the science is still young. Hopefully, this conference, and efforts to follow will greatly advance this science.

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Research Needs in the Southwest Ponderosa Pine Type[1]

Lawrence D. Garrett, W. Wallace Covington, and Aregai Tecle[2]

Abstract.--Research needs for the ponderosa pine/Arizona fescue ecotype of Arizona and the greater southwest is discussed relative to trends in national and regional forest resource demands. National and regional demands on most forest resources are expected to increase. Critical resource demands in the Southwest will involve water, recreation, wildlife, and timber. Research is needed to better understand: the basic ecological interrelationships of forest resources; probable long term implications and cumulative impacts of changing ecologies; long term multi-resource flows from differing silvicultural regimes; impacts of improved utilization of standing timber inventories; improved multiresource management practices; and biodiversities under different managed and nonmanaged forest regimes.

INTRODUCTION

Ponderosa pine is a geographically dispersed conifer, indigenous to all states west of Colorado (Little 1979). The species is prized for its quality wood, which has versatility in framework, sheathing, subflooring, siding, window sash, doors, interior trim, pulp, poles, and timbers. The extensive ponderosa pine ecosystem of the Southwest also provides other critically important resources to the Southwest, including wildlife, fisheries, watershed, recreation, and forage.

The focus of this paper relates to research needs in the southwest ponderosa pine type, more specifically the ponderosa pine/Arizona fescue ecotype of Arizona, New Mexico, and parts of Utah and Colorado (Schubert 1974). Although part of what will be recommended may also be appropriate to other areas, it is not the intent of this paper to make any recommendations for areas outside of the Southwest.

Schubert, in 1974, characterized the state-of-art silvicultural knowledge about this species. He also related the importance of understanding impacts of selected silvicultural methods on other resources. Brown and others (1974) discussed the implications of selected ponderosa pine silvicultural methods on many forest resources, including wildlife habitat, timber growth and yield, scenic quality, water, forage production, and environmental concerns such as sediment yield.

Other writers have investigated specific aspects of the ponderosa pine ecosystem. Ffolliott and Hanson (1968) developed relationships for snowpack development and melt. Baker (1986) provided analysis of long term annual water and sediment yields and expected water and sediment yields under differing silvicultural practices. Minor (1964) and Larson (1975) characterized growth and yield opportunities in southwest Ponderosa Pine in the developed model

[1]Paper presented at the Multiresource Management of Ponderosa Pine Forest Conference, Flagstaff, Arizona, November 14-16, 1989.

[2]Lawrence D. Garrett is Dean and Professor of Forest Economics, W. Wallace Covington is Professor of Forest Ecology, and Aregai Tecle is Assistant Professor of Systems Hydrology, School of Forestry, Northern Arizona University.

PIPO and in site-index curves. Daniel and Boster (1976) characterized near view scenic values of differing overstory and understory management regimes. Patton (1978), Balda and Masters (1980), Cunningham and Balda (1980), and others have contributed to a greater understanding of wildlife habitat relationships in this pine type. Clary (1975) contributed toward understanding forb, grass, and shrub response to differing silvicultural treatments. Sackett (1979, 1980) and Covington and Sackett (1984) have characterized conditions of fire ecology and impacts of prescribed fire. Many other authors have also contributed to understanding individual and joint resource relationships.

Rogers et al. (1984) developed a comprehensive ponderosa pine ecosystem simulator, ECOSIM, which utilized the above research as well as research of many other authors outside the Southwest. A number of individual resource models are linked, to simulate over time the response of the forest multiresources to management actions such as timber harvest, road construction, watershed improvements, and wildlife habitat improvements (Tecle and others 1988).

In referencing the current literature on southwest ponderosa pine, much is captured from research conducted on the Beaver Creek Experimental Area, a 275,000 acre watershed in central Arizona (Garrett 1985). This area lies on basaltic derived soils that are shallower, and not as productive as limestone derived soils found in the eastern mountain region of Arizona, along the Mogollon Rim.

Extensive stands of ponderosa pine in the Southwest exist on limestone soils on which minimal research has been accomplished. These soils are more productive than basaltic derived soils and would be expected to have better yields in all resource areas, such as wildlife, timber, range, etc. (Schubert 1974).

Further, considerable ponderosa pine forests exist in New Mexico, but have received limited research attention when compared to areas in Arizona. These forests are subject to similar demands, but respond to differing natural and human impacts. Similar statements could be made for ponderosa pine ecosystems in southern Utah and Colorado.

Today the extensive ponderosa pine forest of the Southwest must respond to more complex managerial, political, social, and economic stimuli than they have ever had to in history. The issues of public needs and desires, environmental constraints, and resource conflicts will continue as growing forces in defining management direction, and therefore future research direction.

DEFINING FOREST RESOURCE DEMAND

To define future research needs, we should examine where this nation and the Southwest are heading as regards forest resource use, policy, and management. We also need to overview proposed research direction by other writers, to determine how our research needs in the Southwest are supported by and reflected in national direction.

Expected general trends on the nation's public and private forest lands, especially public lands, are as follows (USDA 1989a):

- The area of timber land in the United States will continue to decline. Public lands will decline another 21 million acres by 2040. Total demand for both hardwood and softwood timber in the U.S. and abroad will increase significantly over the next five decades, especially as regards fiber based products such as pulp and structural panels. Pressure will exist to increase total harvests in the United States. Real timber prices will also increase.

  Pressure for greater timber harvests in the Southwest will also increase due to the condition of the resource base, the growing southwest market, and harvest trends in the greater Rocky Mountain Region.

- In general, water is in plentiful supply in the United States, although its distribution as related to agriculture, industry, and population centers does cause difficulties. Most of the difficulties relate to western United States' water supplies, which have been and will continue to be scarce in relation to demand. Water quality is becoming a greater issue, especially as regards nonpoint sources of pollution. Demand for water in the Rocky Mountain Region has increased at twice the rate as the North and Pacific Coast Regions. Water

shortages are projected for the lower and upper Colorado River, the Rio Grande Basin, the Great Basin, and California by the year 2040.

Outdoor recreation will increase in the future as population increases. Use will shift from long vacations to shorter vacations. People will recreate more often, however, they will probably travel shorter distances to access recreation sites. Free access to private lands will continue to decline and associated private land recreation fees will increase. Increased use will occur on public lands. Income growth will increase demand for more costly forms of recreation such as downhill skiing and boating. Growth in wilderness use will stabilize, and possibly decline, as growth in use of wilderness per capita slows due to population age and recreation time becomes more focused around weekends.

The national trends in increased recreation use of public lands are especially appropriate for the Southwest, where population centers are concentrated and expanding rapidly. The relative concentration of population and recreation areas will result in increased vehicular access problems. The greatest impacts will be on those recreation areas and forests adjacent to or near the large metropolitan areas, such as Tucson, Phoenix, Albuquerque, and Los Angeles. Recreation use will continue to diversify, with significant weekend and holiday intensity in all areas. Recreation related to cultural resources will increase as will conflicts related to this use. In general, heavy recreation demand areas will involve water related recreation opportunities. Creating access for an increasing population will become problematic for already heavily impacted areas such as the Salt river impoundments, Grand Canyon, Tonto National Forest, and Colorado River.

Future total demand in the United States for red meat will continue to increase along with the growth in population, with per capita consumption remaining approximately level. Forage supplies from public lands are expected to remain fairly constant over the next several decades. An increasing supply of forage will be sought from private lands, due to continued multiple use conflicts on public lands. Private land quality will continue to decrease.

In the Southwest, most forage for livestock is derived from public lands, due to the minor acreages available in private ownership. Range demand will increase slightly. Multiple use conflicts regarding range on public lands will continue. This is especially true in riparian zones where degradation from grazing continues to be a problem, and in critical wildlife zones where competition from livestock reduces wildlife management capabilities.

- Demand for energy minerals, metallic minerals, and industrial minerals will increase as population increases. Minerals generally exist on a worldwide market where sufficient supplies are available to limit major price rises, except in energy minerals.

  Most of the U.S. coal reserves lie under forest lands in the Appalachian region and northern great plains and most of the metallic minerals lie under forest and range lands in the central and southern Rocky Mountain regions. In the Southwest, metallic minerals will continue to be developed on federal lands as well as some energy minerals. For example, coal, oil and gas, phosphate, molybdenum and precious metals are expected to continue to be mined. Environmental concerns will result in increased conflict. A critical need will exist to determine the impacts of cumulative effects.

In general, the southern Rocky Mountain forest region of the United States will have to respond over the next five decades to similar consumptive patterns of the rest of the United States. However, because the southwest population is expanding more rapidly, and the region already has extensive multiple use, multiresource management conflicts will become major issues in determining planned use.

There will be a continuing need to access public range for livestock use, but livestock/wildlife and livestock/riparian zone conflicts must be resolved. Recreation may become the greatest single resource concern as

population increases and existing recreation areas exceed carrying capacity. Water will be an acute problem and forest and woodland watersheds will be looked to for increased supplies of quality water. Water will also be looked to for increased recreation opportunity, making riparian zones a high conflict area due to their importance for wildlife and fish, humans, livestock, and downstream water use. High quality ponderosa pine timber will continue to be demanded over the next five decades for commercial wood products.

CHARACTERIZING SOUTHWEST FORESTRY RESEARCH NEEDS

As noted above, characterization of present and future demands on forest lands across the United States in effect, captures many demands expected for the southwest region. It is critical that research responds to these near term management problems facing the region. It is also critical that research looks beyond these immediate management issues to discover other opportunities and/or information that can be utilized on future issues and/or problems yet to surface.

A recent report of the USDA Forest Service, the National Association of Professional Forestry Schools and Colleges and the USDA Cooperative State Research Service, listed four general goals for forestry research in the 1990's (USDA 1989a). These are also compatible with forest industry research goals. Together the groups involved account for over 95% of forestry research conducted in the United States. Listed goals are to:

1. Increase the productivity of the forests, and their associated multiresources such as water, recreation opportunity, wildlife habitat, and range resource,

2. Expand domestic and foreign markets for forest products, including primary processed and secondary processed products,

3. Improve the management of forests and associated resources to insure appropriate integration of all forest resource outputs in the best management practice, and

4. Enhance protection of the forest resource base to assure biodiversity and long term ecological stability of the forest ecosystem including forest atmospheric interaction, fire, insects and disease, fisheries, wildlife, TES plants and animals, and water and soil.

We would like to take each one individually, and select a focus that we think is critical to the Southwest.

Increased Productivity of Forests and Associated Resources

Within this goal, we think the Southwest must be concerned in two particular areas; understanding the basic ecological processes of the ponderosa pine ecosystem and gaining better knowledge of the cumulative effects of management.

In basic ecological process research we need to approach the forest as a natural ecosystem under constant man-imposed or natural intervention. We must be able to isolate various processes and factors that are important to sustaining an individual resource, and also those that link it to other resources and characterize the importance of the linkages. For example, what are the interdependent processes by which wildlife are linked to other wildlife and the general forest environment to sustain appropriate energy levels? What are the methods by which water moves through surface and subsurface forest environments to plants, in-stream flows and impoundments? What are the intricacies of the processes, and how are these processes linked to and important for sustaining other resources?

And, second, we must understand with effective research, the cumulative impacts of management. By definition, understanding linked processes and driving factors will help us in this effort. We need to develop models of large forest ecosystems and watersheds that help predict long term effects of forest management practices on forest structure and function.

Critical in this effort are improved survey techniques for gaining multiresource data that have both time and space dependence. Without these improved data it will be most difficult to characterize natural interactive processes across land forms, or monitor cumulative impacts of departures from these natural processes under management action. These data will be critical to effective analysis and model building.

Also of critical importance, system models for modeling biophysical interactions among resources and processes over both time and space must be developed and evaluated. Discriminant analysis, stochastic processes, Delphi technique, linear programming, and data handling tools such as geographic information systems must be brought to bear on the issue. The systems developed will be very helpful in determining interdependencies among forest resources in space and time, in defining research needs, and in formulating less complex multiresource management models, desperately needed by forest planners and managers.

Expand Domestic and Foreign Markets for Forest Products

We do not feel that the Southwest will look toward foreign markets as an outlet for its wood products. However, a significant share of the wood products manufactured in the region are currently shipped to other regions. As the southwest market grows along with U.S. and world markets, opportunities will exist to market more wood products within the region.

Research to increase our current timber utilization level would assist greatly in extending and making more profitable the current resource base. Research on utilization of the timber base in new product outlets that provide higher value added to the region would also be of great benefit.

The five to eleven inch diameter class of ponderosa pine needs to be investigated for appropriate commercial utilization opportunities. Currently insufficient public funds are available to precommercially thin these stands. Yet, without thinning they will significantly affect current and future multiresource diversity and multiresource yields of recreation, wildlife, water, forage, and timber.

A research need is to evaluate how the ecology and productivity of the ponderosa pine ecotype differs across major soil types in the region. A new timber model that can accurately project growth and potential product yields across soils types, precipitation regimes, and landforms would be valuable.

A more progressive look should be taken at the needs and interests of the southwest constituency, and assess how improved silvicultural management can best respond to these needs and interests. That is, what should be the correct mix of wilderness, old growth, and commercial timber base, and what should be the silvicultural management regime for the commercial base. For example, in the commercial timber base, what general basal area management goals should be sought for obtaining best commodity and amenity benefit. We must be cautious in our assessments, especially as regards future needs for resources such as wildlife, timber, and nonconsumptive water uses. Population growth and changes and economic development over time may significantly alter the demand function on these resources.

Improve Integrated Resource Management

This goal captures critically needed applied research in integrated multiresource forest management. It is an area where the research community has generally failed the forest manager. It is also the area where intense conflict will occur over the next several decades unless the research community can provide more and better information regarding appropriate management policies and good definition of the multiresource impacts of management.

Every day, the forest manager must make decisions, and in general, the decisions are acceptable. However, they are sometimes impaired by the lack of good science. The manager faced with this dilemma tries to make the decision so as to minimize the risk of negative impact.

However, the manager does not have the option of not acting. Hunters want to hunt, recreationists want to camp, forest industry needs wood, and wildlife need forage. The management decision process will therefore continue, in spite of the lack of adequate information and expertise for a perfect management decision.

Managers want to improve the decision process. They therefore try to use the best science available. The real dilemma is that science has not kept pace with the overwhelming issues in multiresource forest management.

At least two major research efforts are critically needed in the next decade to address these problems.

1. Policy research on who gets to decide the types of multiresource uses we manage for, and how we implement the decision process.

2. Procedures for determining best multiresource management practice

There are many questions in the policy research arena, but two seem critical.

1. Where should the authority best reside for determining the proper multiresource use for public lands in the southwest region? The U.S. general public, the southwest general public, U.S. Congress, the states, the courts, professional foresters, or all of the above? If all of the above, then which groups have the right to decide what part of the issue? How should the authorities be distributed?

2. If we can approach a solution to the first question, that is, who gets to decide, then we should resolve a second question: what is the best implementation process for accomplishing it. For example, one necessary step to implementing multiresource management would be to determine how much timber should be harvested. If each state were given the authority to decide the annual harvest level in the state, how should they arrive at the decision? Should it be done by passing a law? Popular vote? Congressional or executive mandate? Binding arbitration?

If we can assume that we can determine who has the right to decide the mix of uses, and how they get it done, then somehow, we must determine the best multiresource management practice for attaining the goal. Anyone who is now in this science area knows the practice must respond to three critical needs.

1. The research and management direction must incorporate understanding of many multiresources, and their individual and joint productivities over time and space. The research process must merge the talents of researchers and managers from the concept phase, and research must be carried out on large areas such as watersheds, not on individual plots.

2. In the near term the management direction must be definable with differing resolutions of data input, and it must accommodate planning needs at a forest level (one million+ acres) and implementation needs at a project level (1,000 - 5,000 acres). Further the rationale and process in the various approaches must be congruent in their direction.

3. Analytic systems must be a central methodology in the process to assure timely, reproducible results that are cost effective, rational, consistent, and understandable.

Assure Biodiversity and Ecological Stability

What the general public, and all forest constituency would like in the Southwest and other regions is maximum biological diversity and a stable ecology, while maintaining support to important social and economic interests at satisfactory levels. For example, there is a need for the Tonto National Forest to serve as many social and economic needs or desires as possible, while at the same time maintaining its biophysical diversity, and physical and ecology base. Is this being accomplished? Considering the demand level, yes, but there is always the need to do a better job.

In the southwest ponderosa pine type, the research goals for biological diversity need better definition. This relates to the fact that biological diversity today across the ponderosa pine ecosystem is an artifact of man's intervention. This is primarily due to fire management, but also relates to long term timber, recreation, range, and water management activities. That is, it may be difficult to define, much less strive for a biological diversity that existed before man's intervention, since today we have almost 100 years of fire management. The definition then, will probably ascribe more to a managed state.

Second, the southwest forest based constituency may or may not want the biodiversity of the original unmanaged forest or the current managed forest. This needs to be determined.

Whatever forest biodiversity is desired, it will need better definition. This will require considerable ecological research to contrast biodiversities of various managed forest states across space and time streams. That is, although biodiversity in an overmature old growth forest is somewhat steady state, managed forest biodiversity constantly changes over time. Investigations of differing silvicultural systems and their time stream biodiversities are required to answer the above question.

Understanding the stability of the ecology and physical reserve base also requires more research effort, especially as regards cumulative effects over time. Overall, we do not seem to have a severe problem. That is, we are a class one airshed, we have limited toxic waste dumping, our water is relatively clean, and tree harvest, mining, and agriculture are well managed. That is, in contrast to New Jersey and southern California our ecology is probably more stable and receiving less impact.

However, research problems are surfacing at an alarming rate, and need to be addressed. Research in the following areas, in particular, need immediate attention.

- Air quality, especially as regards visual quality, needs more research. Prescribed fires, dust, and stack emissions need more evaluation to determine their combined impacts on our airshed over time.
- Water quality is an issue that will continue to create increased problems as regards sediment loads and dissolved toxins.
- Riparian ecologies are a critical issue throughout the state due to vacillation of instream flows and conflicts over multiple use (fisheries, grazing, tree harvest, nonconsumptive and consumptive water management).

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Areal Growth and Distribution of Ponderosa Pine Forests: Moderator's Comments

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The modern distribution of ponderosa pine consists of large, discontinuous populations established over a wide area of the western United States and southwestern Canada. Fossil records of the species indicate distributional changes have occurred during the last 10,000 years. The establishment of large populations within the arid Southwest may be a function of the development of the summer precipitation maximum during the monsoon.

Throughout its range, ponderosa pine is an important species, not only for its commercial timber value, but the forests are also used for recreation and to provide forage for wildlife and domestic livestock, and it is also cover for wildlife. Logging and grazing practices since the 1850s, as well as fire control, have altered the forest structure and species composition. Timber harvest practices have resulted in an uneven-aged structure with dense smaller trees and a low density of snags. Livestock grazing has contributed to changes in vegetation structure, species composition, and fire response. Fire control has resulted in the increase of white fir and juniper in pine forests, especially in California.

Little thinning was done in Southwestern ponderosa pine forests until the 1950s. A series of thinning guides have been developed and used since that time.

Long term growth records are becoming increasingly important to understanding tree and stand growth trends under changing environmental or climatological conditions. Analysis of dendrochronological data have undergone recent statistical improvement with the incorporation of extensive computer editing and Kalman filter algorithms.

Development of the Southwestern Ponderosa Pine Forests: What Do We Really Know?[1]

R. Scott Anderson[2]

Abstract.--The modern distribution of ponderosa pine (*Pinus ponderosa*) consists of large, discontinuous populations within the western United States and southwestern Canada. However, the former distribution and abundance of the species over the last 14,000 years is not well known. The Southwestern and Rocky Mountain variety exhibited a latitude and altitudinal expansion after ca. 10,600 yr BP, while present evidence is insufficient to confirm other than a predominantly altitudinal expansion of the tree in the Sierra Nevada of California.

INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Laws.) is one of the most widely distributed trees within montane western North America, occurring from northern Mexico into southern British Columbia (fig. 1; Little 1971). The species is separated geographically and genetically into at least two distinct varieties (Critchfield 1984). *Pinus ponderosa* var. *ponderosa* occurs mainly in California and the Pacific Northwest, while *P. p.* var. *scopulorum* occurs within the Rocky Mountain region, Utah, New Mexico and Arizona. These varieties are sympatric only in central Montana. A third variety, *P. p.* var. *arizonica*, is described from southeastern Arizona (Kearney and Peebles 1951), but is largely a Mexican form.

Although an important tree from the standpoint of lumber production and recreational value, with a large literature on the silviculture of the species, little is known regarding the fossil history of ponderosa pine, or the history of the vegetation type in general. How long have these forests been established? What was the glacial-age distribution of the species? What was the postglacial pattern of migration into the Southwest since the last glacial age? What can be determined regarding the glacial refugium of the tree? This paper reviews the literature on the subject, compiled since the brief discussion by Critchfield (1984), and concentrates on the Sierra Nevada of California and at sites within Arizona and surrounding states. I also present new data for the two areas, suggesting minimum ages for the establishment of the tree within its modern range in California, and of the ponderosa pine forest type on the Mogollon Rim, Arizona.

Modern Occurrence in Arizona and California

In the Sierra Nevada of California, *Pinus ponderosa* var. *ponderosa* occurs on relatively xeric sites within the Sierra Montane forest. In the northern part of the range, it grows in a belt from 300 - 1800 m (980 - 5900 ft) elevation, rising to 1200 - 2100 m (3900 - 6900 ft) as far south as Sequoia National Park (Rundel et al. 1988). Modern associates include white fir (*Abies concolor)*, douglas-fir (*Pseudotsuga menziesii)*, California black oak (*Quercus kelloggii*) and incense-cedar (*Calocedrus decurrens*), among others. Unlike areas of the southern Colorado Plateau in Arizona, ponderosa pine rarely occurs in pure stands in California. Details of the history of the Sierra Montane forest type are found elsewhere (Anderson 1987, 1990).

The largest continuous stand of the species is found within northern Arizona, along the southern margin of the Colorado Plateau, an unbroken band of trees ca. 40 to 65 km wide and

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nearly 480 km long (Cooper 1960). This dominant constituent of the Sierra Montane Conifer Forest (Brown and Lowe 1977) occupies much of the mountain and plateau country above ca. 1980 m (6500 ft). Above ca. 2590 m (8500 ft), ponderosa pine is largely replaced by douglas-fir, white fir and other species.

Within northern and central Arizona, the typical form *P. ponderosa* var. *scopulorum* Engelm. is most common (Kearney and Peebles 1951). This form differs from other populations within the Rocky Mountains in having three needles per fascicle instead of two (Haller 1965). However, in the mountains of several southern Arizona counties--Graham, Cochise, Santa Cruz and Pima--the common form is var. *arizonica* (Engelm.) Shaw, which has five needles per fascicle. In certain mountain ranges, such as the Santa Catalina Mountains of Pima County, both forms are reported.[3]

Determining Late Quaternary Plant Distributions

Records of plant biogeography and vegetation change during the late Quaternary are obtained in two ways. Pollen and plant macrofossils are often found in stratigraphic deposits, usually lake and alluvial sediments laid down within a basin or along a stream course. Many of our longest vegetation records

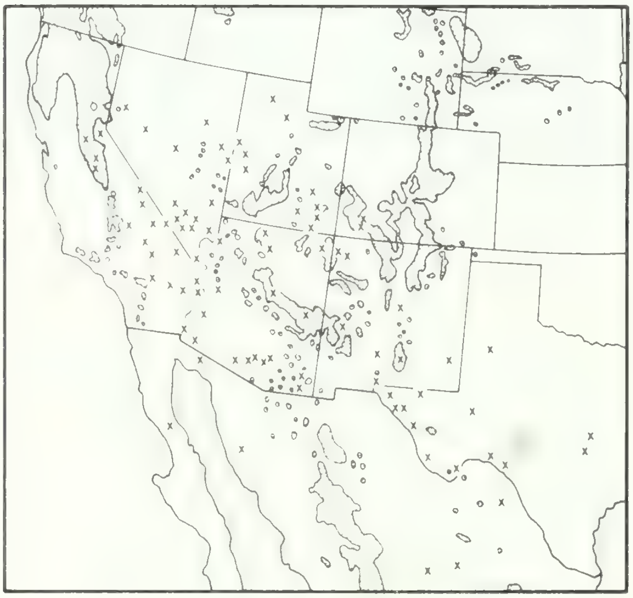

Figure 1.--Modern distribution of ponderosa pine in the Southwest and California (stippled after Little 1971) with the distribution of fossil packrat and pollen sites, (x-mark; after Spaulding et al. 1983, Van Devender et al. 1987, Anderson unpublished).

[3]Van Devender, T.R. 1989. Personal conversation. Arizona-Sonora Desert Museum, Tucson, Ariz.

are deduced from the analysis of stratigraphic deposits. In addition, the deposits generally represent uninterrupted sedimentation, allowing the paleoecologist to "view" vegetation change at short intervals. One problem is that continuous deposits, particularly lacustrine deposits, are uncommon in much of the arid Southwest. In Arizona, natural lakes are confined to areas along the Mogollon Rim, the Kaibab Plateau, the White Mountains and other high elevation areas of the region. Playa lakes, such as Willcox Playa in southeastern Arizona (Pluvial Lake Cochise during the last glacial episode), occupy some lowland basins. Lakes from mid-elevations (i.e., Montezuma Well, Pecks Lake in Yavapai County, Arizona), are rare and occur only under specialized conditions. Conditions within the Sierra Nevada are much the same, with sedimentary basins confined largely to ca. 1980 m (6500 ft) and above.

Packrat (*Neotoma* sp.) midden deposits are abundant throughout the lower elevation deserts, and also preserve pollen and plant remains in excellent condition. Packrats are prolific collectors of plant materials within 30 - 50 m of their nests (Finley 1958; Bleich and Schwartz 1975). These deposits are generally confined to rocky shelters and scarps, and are rarely preserved in the valley bottoms or exposed locations. In addition, middens are not deposited continuously; depositional events (formation of middens) may be separated by hundreds to thousands of years. However, most of the vegetational history of the lowland regions of the area has been deduced from the analysis of these middens (Van Devender et al. 1987). More than 1,100 packrat middens have been analyzed and radiocarbon dated (Webb 1985).

With the analysis of fossil assemblages contained within stratigraphic deposits and packrat middens, placed into a temporal context with radiocarbon dating, the picture of vegetation change within the desert Southwest has come into greater focus. However, large gaps within this story still occur. One of these stories is that of ponderosa pine.

THE LATE QUATERNARY FOSSIL RECORD OF PONDEROSA PINE

Though today ponderosa pine is perhaps the most conspicuous conifer at mid- to higher elevations within the region, the fossil record of the tree is largely unknown. Axelrod (1988) recorded *Pinus* cf. *ponderosa* remains of Miocene age from west-central Nevada, with additional locations of Pliocene age. The earliest Quaternary record, estimated at >100,000 years old, is that of Baker (1986), who found remains in Sangamonian-age sediments within Yellowstone National Park, Wyoming; the tree presently does not grow within that park. Of the nearly 75 packrat midden and ca. 20 stratigraphic deposits within the desert Southwest and Sierra Nevada of

California (fig. 1; Spaulding et al. 1983; Van Devender et al. 1987; Anderson, unpublished), only a handful contain definitive presence of ponderosa pine during the latest glacial episode (late Wisconsin).

The oldest of these sites occurs in California where needles of the tree were found in packrat middens dating 12,500 to >45,000 yr BP (fig. 2; Kings Canyon, 980 - 1280 m; 3215 - 4200 ft; Cole 1983), occurring several hundred meters below its modern limit. Ponderosa pine grew at Log Meadow (2086 m, 6840 ft; Sequoia National Park) by ca. 11,150 yr BP (Anderson, unpublished), and near the Meadow of Honor (1875 m, 6150 ft; Kings Canyon National Park) by ca. 10,125 yr BP (Anderson, unpublished). Further north in Yosemite National Park, remains as old as ca. 12,200 yr BP were recovered from sediments of Swamp Lake (Smith 1989; Anderson, unpublished). Since the tree grows near the lake today (1554 m; 5100 ft), a minimum date is provided for the arrival of the species within its modern elevational range. In all cases except Swamp Lake, ponderosa pine was found in association with remains of other tree species with which it grows today. Thus, plant associations within the modern Sierra Montane forests of California had begun to coalesce by the end of the late Wisconsin (Anderson 1987, 1990).

Outside of California, late Wisconsin records of the tree are equally rare (fig. 2). In the San Andres Mountains of New Mexico (1705 m; 5590 ft) today a transition between desert grassland and pinyon - juniper (*Pinus edulis - Juniperus monosperma*) woodland,

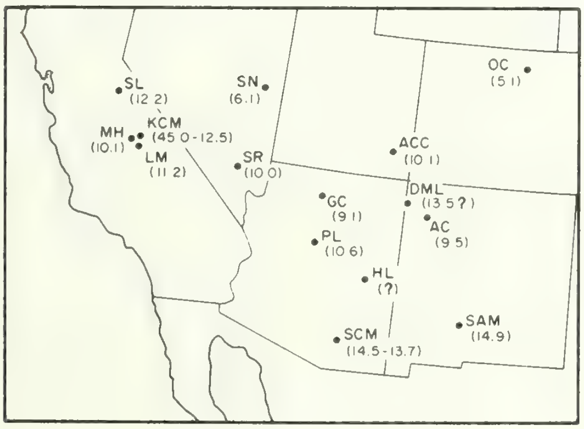

Figure 2.--Fossil distribution (first occurrence) of ponderosa pine with radiocarbon ages (yr BP x 1000); SN = Snake Range; SR = Sheep Range; OC = Owl Canyon; ACC = Allen Canyon Cave; GC = Grand Canyon; DML = Dead Man Lake; AC = Atlatl Cave; PL = Potato Lake; HL = Hay Lake; SCM = Santa Catalina Mts.; SAM = San Andres Mts.; SL = Swamp Lake; MH = Meadow of Honor; KLM = Kings Canyon middens; LM = Log Meadow.

Van Devender (1990a) reported ponderosa pine needles associated with douglas-fir, Colorado blue spruce (*Picea pungens*) and one-seeded juniper (*Juniperus monosperma*) in a single midden dating ca. 14,920 yr BP. The fossil needles are of the "scopulorum" type. Pollen identified as ponderosa pine was found in sediments of Deadman Lake (elevation 2780 m, 9120 ft); Chuska Mountains, New Mexico), estimated at ca. 13,500 yr BP (Wright et al. 1973). Ponderosa pine grows around the lake today. No plant macrofossils were found in the sediments to confirm local presence; identification of the pollen to species was based on pollen morphological characteristics alone (Hansen and Cushing 1973).

In the Santa Catalina Mountains near Tucson, southern Arizona, ponderosa pine needles, as well as remains of Arizona cypress (*Cupressus arizonica*) and douglas-fir, were found in packrat middens from modern desert grassland (elevation 1555 m; 5100 ft), dating ca. 14,450 to 13,670 yr BP (Thompson and Van Devender 1982; Van Devender 1990b). These midden records do not reflect significant changes in the plant distributions, though, as the tree can be found in more mesic canyon sites at nearly the same elevation today. As at the San Andres site, the remains are of the "scopulorum" type, not the "arizonica" variety most common in the range today.[4]

Jacobs (1983) utilized palynological techniques to identify the presence of diploxylon pine-type (includes both ponderosa and lodgepole pine, *P. contorta*) pollen in sediments of Hay Lake, Arizona, (elevation 2780 m; 9210 ft), deposited by ca. 29,000 years ago. She suggested a more widespread occurrence at lower elevations of either or both species since near alpine conditions occurred around the lake at that time. No plant macrofossils were found to confirm presence, however; only ponderosa pine grows near the lake today.

In northern Arizona, diploxylon-type pine pollen may have been present in sediments of Crane Lake (elevation 2590 m; 8500 ft) as early as ca. 11,000 yr BP (Shafer 1989). Irregularities in radiocarbon dating of the profile suggest caution in interpretation, however. Betancourt (1984) recorded ponderosa pine needles at Allen Canyon Cave, southeastern Utah (elevation 2195 m; 7200 ft), in a midden dating ca. 10,140 yr BP. Nearby Fishmouth Cave (1585 m; 5200 ft) did not have ponderosa pine remains, although the record stretched back to ca. 12,770 yr BP.

At other Southwestern sites, however, ponderosa pine did not become abundant until somewhat later in the early Holocene. These

[4]Van Devender, T.R. 1989. Personal conversation. Arizona-Sonora Desert Museum, Tucson, Ariz.

include the Sheep Range in southern Nevada (2400 m; 7875 ft; by 10,060 yr BP; Van Devender and Spaulding 1979), Atlatl Cave, Chaco Canyon, New Mexico (1910 m; 6270 ft; by 9500 yr BP; Betancourt and Van Devender 1983) and the eastern Grand Canyon, Arizona (1770 - 1900 m, 5800 - 6230 ft; by 9100 yr BP; Cole 1982). Changing climate no longer favored ponderosa pine at the Grand Canyon sites after ca. 8430 yr BP, while the species was extirpated locally near Atlatl Cave by ca. 2400 yr BP.

Somewhat further to the north, the species grow in the Snake Range of eastern Nevada by 6120 yr BP (2040 m; 6700 ft; Thompson 1984). It occurred at Owl Canyon near Ft. Collins, Colorado, by 5090 yr BP (1860 m; 6100 ft; Betancourt 1987) and in southeastern Wyoming by 4060 yr BP (Wells 1970).

These observations suggest two hypotheses. First, ponderosa pine was probably absent or extremely rare on the Colorado Plateau and northerly locations during the latest Wisconsin (ca. 11,000 - 14,000 years ago), and that the extensive forests of today all date subsequent to that time period. Second, the species exhibits a different biogeographic history in the Sierra Nevada of California than on the Colorado Plateau and in southern Arizona and New Mexico. The first observation will be discussed in light of a continuous sediment record from a small lake near Flagstaff, Arizona. The second will be discussed subsequently.

THE RECORD FROM POTATO LAKE, ARIZONA

Potato Lake is a small solution feature within the Permian Coconino Sandstone, Coconino County, Arizona. At 2222 m (7290 ft) elevation, it is near the average elevation of the Mogollon Rim. Thus, the record of vegetation history of the basin should be typical of the southern margin of the Colorado Plateau in general. Sediments from this site were originally studied by Whiteside (1965), who identified the pollen and microalgae assemblages deposited there over the last approximately 15,000 years. With these new data (Anderson et al. 1989), the record is extended back to ca. 35,000 yr BP, into the last interstadial (middle Wisconsin). This is important because the middle Wisconsin is thought to have been a warm interval. I wondered if the mid-Wisconsin interval was warm and/or wet enough to support ponderosa pine forests as today. These new data include not only pollen but plant macrofossil remains as well, establishing local presence of several western conifers.

During the mid-Wisconsin interval (pollen Zone I; ca. 35,000 to 23,500 yr BP), dominant pollen types are spruce (*Picea*, needles of *P. englemannii*, fir (needles of *Abies concolor*, large haploxylon pine (*Pinus*), juniper, oak, sagebrush (*Artemisia*), other Compositae and grasses (Gramineae) (Anderson et al. 1989; fig. 3). Macrofossils of douglas-fir are also found. Diploxylon pine pollen, represented by either ponderosa or lodgepole pine, is conspicuously absent.

During Zone II, the late Wisconsin cold interval dated here ca. 23,500 - 10,400 yr BP, dominant pollen types are spruce, fir, large haploxylon pine, sagebrush, pinyon pine and Chenopodiaceae-*Amaranthus*. Only macrofossils of Englemann spruce are found.

However, by 10,400 yr BP (pollen Zone III), pollen of boreal conifers (spruce, fir, haploxylon pine), as well as sagebrush, is very much diminished. Instead, dominant pollen types are diploxylon pine (represented by the first occurrence of ponderosa pine needle fragments by ca. 10,600 yr BP), oak, grasses and other composites. Higher percentages of aquatic and wetland plants, such as *Potamogeton* (pondweed), *Typha latifolia* (cattail), Cyperaceae (sedge) (Anderson, unpublished; Whiteside 1965) indicate much lowered lake levels. Sediment accumulation rates drop considerably and a hiatus of deposition may be apparent for the early Holocene, i.e., the lake may have dried completely.

This three part zonation of vegetation for the Mogollon Rim area over the last 35,000 years can be summarized as follows: An open Englemann spruce - white fir - douglas-fir forest, with an understory of sagebrush, grasses and composites, existed around Potato Lake during the mid-Wisconsin interstadial. Although the record of wetland and aquatic plants indicates relatively high lake levels (relatively wet conditions), the climate was neither warm enough nor perhaps wet enough during the summer to allow the establishment of ponderosa pine on or near the Mogollon Rim at this elevation. During the late-Wisconsin cold period (ca. 23,500 - 10,400 year BP), colder climatic conditions intensified, allowing Englemann spruce to predominate near the lake. I interpret this assemblage as representing a closed spruce forest, with additional mixed conifers occurring in very low abundance. A ponderosa pine forest became established sometime after 10,600 yr BP, with the immigration of ponderosa pine into the watershed of Potato Lake. This forest may have been somewhat different than today, with perhaps more oak and greater forest openings occupied by non-arboreal plants such as grasses and composites. This also establishes the time of origination of the modern biseasonal precipitation regime, the summer precipitation maximum called the "Arizona Monsoon" (Sellers and Hill 1974).

LATE QUATERNARY BIOGEOGRAPHY OF PONDEROSA PINE

Although the fossil record of ponderosa pine through time is only sporadically docu-

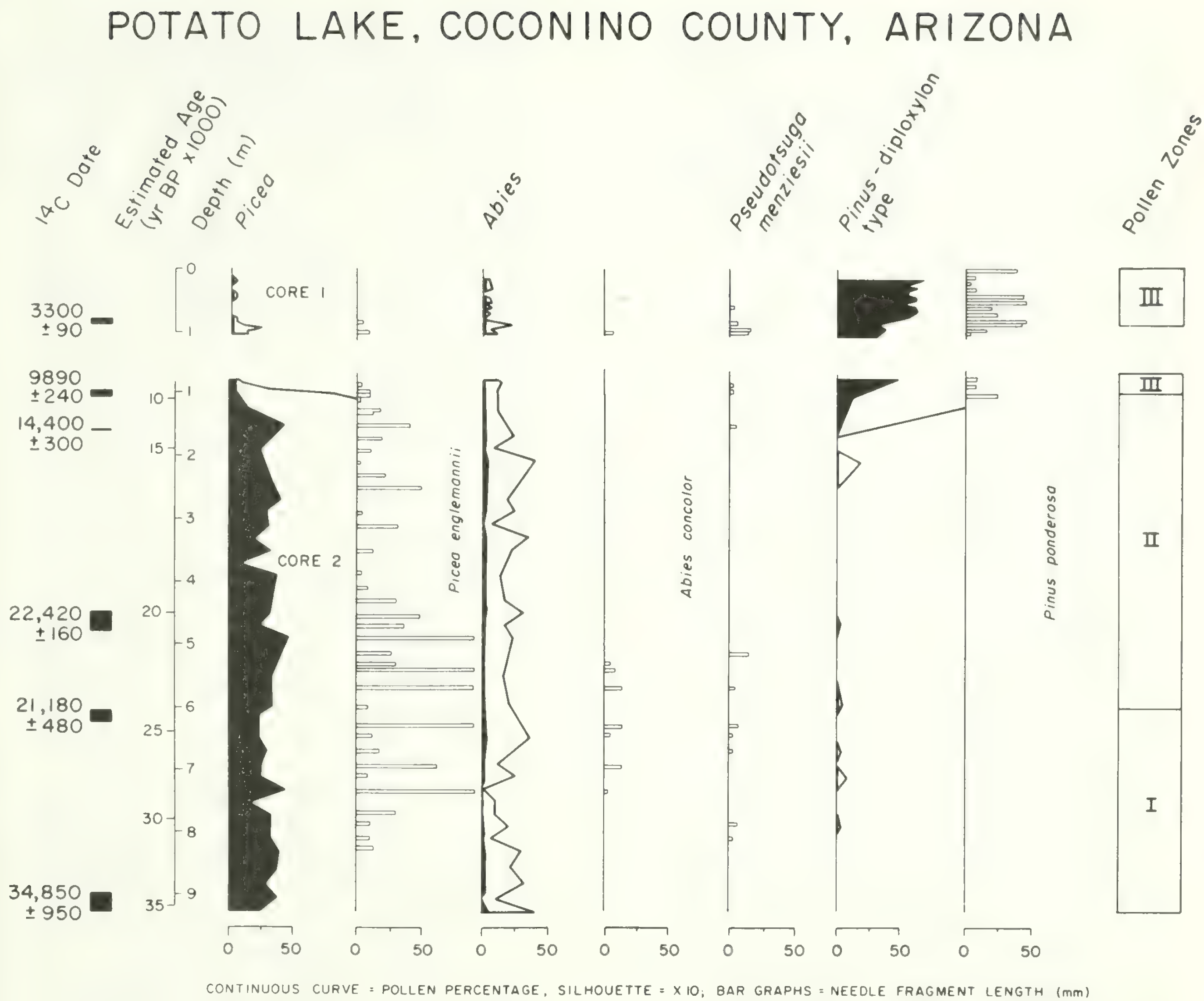

Figure 3.--Pollen and plant macrofossils of selected conifers from the Potato Lake, Arizona, sediment cores. Estimated age scale as in Anderson et al. (1989).

mented in the Southwest and California, it is apparent that the late Quaternary history of the species has been different between the two areas. For California, ponderosa pine has been found largely within the same geographic area for at least the last 45,000 years (figs. 1 and 2). However, during the mid- and late-Wisconsin, the tree grew at considerably lower elevations (980 - 1280 m) than it presently does. The tree became established within its present elevational range ca. 11,000-12,000 years ago. Apparently the gentle western slopes of the northwest - southeast trending Sierra Nevada range allowed for simple downslope migration in response to climatic cooling during the Wisconsin (Tioga) glacial episode and upslope migration during the present interglacial. Data are not sufficient to evaluate the possibility of southward migration also during the last glaciation.

The situation within the American Southwest suggests that ponderosa pine probably underwent a more radical southward migration there during the last glacial episode. The oldest records are found in middens from southeastern Arizona and southcentral New Mexico. All other records except Deadman Lake and Crane Lake suggest establishment of ponderosa pine on the Colorado Plateau no earlier than 10,600 yr BP. The estimated age from Deadman Lake (fig. 3; Wright et al. 1973) is based on interpolation between a Wisconsin-age date and the present, and may be

in error by several thousand years. Dating problems also occur for Crane Lake (Shafer 1989; see above). Neither of these ages are supported by direct occurrence of plant remains themselves, only by pollen data, while the other ages are based on occurrence of plant macrofossils alone or with pollen of ponderosa pine. Indirect evidence also comes from absence of ponderosa pine in virtually all of the packrat midden series from elevations lower than its modern range for the Wisconsin (Van Devender et al. 1987). It almost certainly did not retreat to lower elevations and expand on valley bottoms within the region (Betancourt and Van Devender 1983; Betancourt and Davis 1984), as originally suggested by Martin and Mehringer (1965) and Wright et al. (1973). It is possible that it survived in isolated, mesic habitats, an idea proposed for pinyon pine by Cinnamon and Hevly (1988). However, no direct evidence has been found to support this hypothesis.

Just as the actual Wisconsin refuge remains a mystery, so does the immigration of *P. ponderosa* var. *arizonica*. This predominantly five-needled pine is the most common variety within the Santa Catalina Mountains of southern Arizona today. However, both the late Wisconsin middens from that location and the San Andres Mountains of New Mexico contain exclusively the three-needled variety, *P. p.* var. *scopulorum*[5] Whether this suggests the development of var. *arizonica* during the Holocene, or is a result of a paucity of samples cannot be answered without more data.

The modern distribution of ponderosa pine within the Southwest has often been linked to the areas receiving significant summer precipitation (Betancourt 1984; Shafer 1989). This "Arizona Monsoon" (Sellers and Hill 1974) impacts an area roughly bounded on the east by the Colorado River and Colorado Plateau, on the north by southern Wyoming and to the east by the Colorado Front Range (Mitchell 1976). Climatic models (Kutzback and Guetter 1986; COHMAP 1988) and empirical data (Spaulding et al. 1983; Spaulding and Graumlich 1986) suggest a greatly weakened monsoon during the glacial maximum over that of today. An intensified monsoon during the latest Wisconsin and early Holocene, along with climatic warming, undoubtedly created the opportunity for the expansion of ponderosa pine in that region.

This is not the case for ponderosa pine in California, which does not experience significant summer precipitation today (Major 1988), and was apparently drier during the early Holocene (Davis et al. 1985; Anderson 1987, 1990). Clearly summer precipitation has not been a limiting factor here. Perhaps winter precipitation has been sufficient, enabling soil moisture levels to remain high enough for ponderosa pine establishment. Alternatively, genetic differences between the California and Southwestern varieties of ponderosa pine (see Critchfield 1984) may account for these responses to changing climate.

[5] Van Devender, T.R. 1989. Personal conversation. Arizona-Sonora Desert Museum, Tucson, Ariz.

CONCLUSIONS

The distribution of ponderosa pine in the Southwest was strikingly different during the last glacial episode. The tree was largely absent from much of its modern range during that time. Although no direct fossil evidence has been found, it may have survived south of the Santa Catalina Mountains of Arizona, and expanded northward coincident with the onset of climatic warming and intensification of the summer monsoon. Alternatively, ponderosa pine survived in very isolated, mesic microhabitats within or near its modern range and from which we have no substantiated fossil record. Somewhat different conditions prevailed in the Sierra Nevada of California, where remains of tree are found dating back to 45,000 years ago. Thus, the eastern populations of the species exhibited a largely latitudinal (and undoubtedly altitudinal) expansion while present evidence is insufficient to confirm other than a predominantly altitudinal expansion of the tree in California.

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The Development of Thinning Practices in Southwestern Ponderosa Pine[1]

Ernest A. Kurmes[2]

Abstract.--Little thinning was done in the dense sapling stands of ponderosa pine in the southwest until the 1950's due to economic considerations and the influence of USFS researcher G.A. Pearson, who favored only very light crop tree thinning. In the past 35 years a series of thinning guides have been developed which have recommended increasingly heavier, uniform thinnings to promote more rapid diameter growth.

Early reports of the southwestern ponderosa pine forests described open forests with well-spaced trees. This condition was probably due to frequent surface fires. With frequent fires little fuel accumulated, particularly under stands of young trees which were not yet producing large amounts of litter each year, so few trees were killed and those that were usually were the smallest and least desirable. Although the fires did not kill trees uniformly or selectively, some thinning was accomplished.

A major goal of foresters in the southwest after the establishment of the national forests was the prevention of wildfires. We were quite successful in meeting this goal, but along with the benefits of reduced fire losses, the effects of fire thinning disappeared. Natural regeneration occurs at intervals, when the requirements of a good seed crop, a desirable seedbed, and adequate rainfall are all met. In the southwest, the most exceptional conditions for natural regeneration occurred when heavy seed production in the fall of 1918 was followed by a warm, wet spring and summer in 1919. Soil surface conditions were probably also unusually good because of heavy grazing during World War I. As a result, thousands of seedlings per acre were established on most of the open areas of the ponderosa pine forests. While natural mortality of trees overtopped by their neighbors occurs with most species of trees, this has happened very slowly in the 1919 seedling stands. A report in 1960 stated that 9000 stems per acre was "probably more or less representative of the density of pine thickets in the White Mountains" at age 38 (Cooper, 1960). A tally of dense "doghair" near Flagstaff at age 60 in 1979 showed the following distribution by diameter classes:

Diameter Class (inches)	Number of Trees Per Acre
1	1043
2	902
3	618
4	333
5	218
6	114
7	74
8	52
9	26
10	13
11	9
12	3
13	3
TOTAL	3408

Average diameter 3.3", 204.5 sq. ft. basal area; largest 150 trees, average diameter 8.5", 59.5 sq ft. BA

Although some trees grew well on this acre, the many small trees have been using water and nutrients and have restricted the growth of the larger trees. For example, in this illustration the 300 largest trees range from 5 to 13 inches in diameter and average 7.4". If the stand had been precommercially thinned to 300 trees per acre at age 15, we might reasonably expect it to average 11" in diameter at age 60.

[1]Presented at the Symposium on Multiresource Management of Ponderosa Pine. (Northern Arizona University, Flagstaff, November 14-16).

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History of Thinning in the Southwest

The earliest recommendations for thinning were made by G.A. Pearson, research forester at the Fort Valley Experimental Forest. Thinning always involves some compromise between diameter growth and natural pruning and form. Pearson's attitude was expressed as follows:

> "During the pole stage, when the stems are shaping up, diameter growth is secondary to form and natural pruning. Dense stocking should be the rule. Overstocking in this stage is preferable to understocking, because in the former case, dominants usually assert themselves. If, as a last resort, thinning becomes necessary, removal of only enough stems to encourage the development of dominants will break the deadlock." (Pearson, 1950, page 29).

Uniform thinning had been the rule but very little had been done. Beginning in the 1930's, Pearson recommended a very conservative form of crop tree thinning involving only the removal of competing trees very close to the selected crop trees. Crop tree thinning developed as an economical way to obtain the benefits of thinning at a time when it could be accomplished only by chopping down the trees to be removed. Pearson (1935) contended that it took 30 man-hours of labor per acre to uniformly thin a pole-sized stand while only 8-3/4 hours would have been required for a crop tree thinning. Although he acknowledged the role of deficient soil moisture in limiting tree growth, Pearson felt so strongly about the beneficial effects of competition on stem form and pruning young stands that he did not recommend thinning around dominant trees, and suggested removing only trees whose crowns would touch those of selected codominant and intermediate crop trees. Heavier thinnings to stimulate diameter growth were recommended after the trees reached commercial size of 12" in diameter and 40 to 50 feet in height. Pearson's influence on silvicultural practice in the Southwest was very great and little other thinning research was done during this time.

After Pearson's death in 1949, other foresters began to recommend earlier, heavier, uniform thinning of dense pine stands. In 1954 E.M. Gaines and E.S. Kotok of the Rocky Mountain Forest and Range Experiment Station published their suggestions, based on a study of all the available data from thinning experiments in the Southwest. The expected development of a market for pulpwood was economically encouraging for uniform thinning. Their recommendations were to leave 600 trees per acre in a precommercial thinning, which would be allowed to grow to an average diameter of 7 inches (160 square feet of basal area) followed by commercial thinnings with a residual basal area of 80 square feet. The U.S. Forest Service followed this guideline for many years, but modified it in doing precommercial thinnings by leaving all trees 5" and larger with the thought that these trees could soon be cut in a commercial pulpwood thinning. As a result, many stands were left with much more than 80 square feet of basal area per acre. Because pulpwood removal has proceeded much more slowly than was expected, some of these stands have never been thinned a second time.

In 1962 the Rocky Mountain Forest and Range Experiment Station established the Taylor Woods thinning plots near Fort Valley (Schubert 1971; Ronco et al. 1985). These plots include 3 replications of 6 different growing stock levels (GSL), ranging from an extreme of excessively heavy thinning (30 GSL) to one of very light thinning (150 GSL). Growing stock levels are identified by numbers representing the residual basal area after thinning when the stands average 10 inches or larger at breast height. When the average diameters of the stands are less than 10 inches lower residual basal areas are required, as indicated in figure 1. This heavier thinning in stands with low average diameters was intended to allow for a reasonable growth rate up to the time the stand could be thinned commercially.

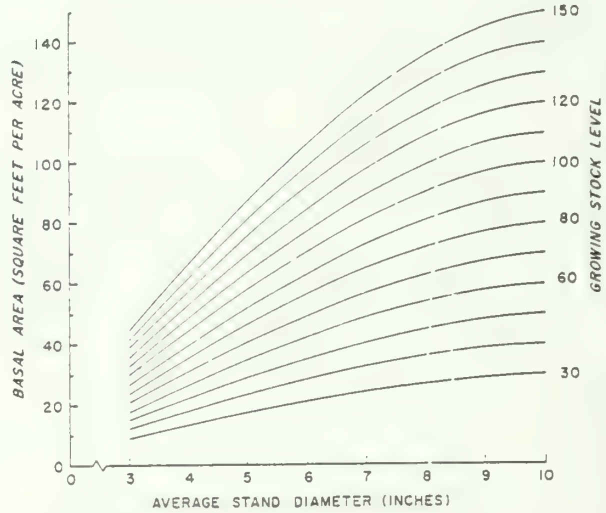

Figure 1. Basal area after thinning in relation to average stand diameter. (Modified from Myers, 1967.)

Based on ten-year results from Taylor Woods, the Southwestern Region of the U.S. Forest Service adopted GSL as a guide to precommercial thinning. The recommended GSL varied with site index: site index 81 or more - GSL 100, site indexes 61 to 80 - GSL 80, site indexes 60 or less, GSL 60 (USFS 1977). Within a few years the Forest Service developed thinning schedules which left only 275 trees per acre in precommercial thinnings and then followed GSL curves. This eliminated the variation

in average spacing with different average stand diameters, simplifying the directions for thinning crews. It also avoided the retention of excessive numbers of trees in stands with very small average diameters. However, it was shortly determined that leaving only 275 trees per acre on very good sites cost a potential commercial thinning, so the residual number of trees was raised to 325 on areas with a site index greater than 79 (USFS 1981). On these highest sites, the stand was grown at GSL 80 after the first commercial entry, while stands with site indexes between 66 and 79 were managed at GSL 60 and those below site index 66 at GSL 50.

More recently (USFS 1985), a new set of stocking charts for southwestern ponderosa pine has been developed based on the Gingrich stocking guide (1967). For areas with a site index equal to or greater than 70, precommercial thinning to 325 trees per acre is recommended, while 275 TPA is recommended for stands with a site index below 70. Upper and lower limits of the management zone are defined as densities relative to average maximum density, a curve based on Reineke's stand density index (Reineke 1933). The major advantage of these curves is that they allow for increasing residual basal areas in stands above 10 inches mean diameter.

Thinning trends in the southwest have followed trends elsewhere in the United States. Precommercial thinning has become heavier and later thinnings follow a line of increasing residual basal area, with some variation allowed for differences in site. As more data from thinning studies become available, we can expect to see further refinements in stocking guides for southwestern ponderosa pine.

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Historical Effects of Forest Management Practices on Eastside Pine Communities in Northeastern California[1]

William F. Laudenslayer Jr.,[2] Herman H. Darr,[2] and Sydney Smith[3]

Abstract.--The eastside pine regions of northeastern California, characterized by stands of ponderosa (Pinus ponderosa) and Jeffrey (P. jeffreyi) pines, have long been influenced by timber harvest, fire suppression, and domestic livestock grazing. These activities have substantially altered the structure and composition of eastside pine stands, and will affect options for management in the future. Before settlement by emigrants (beginning about 1850), eastside pine stands were commonly composed of relatively open stands of large ponderosa or Jeffrey pines, sometimes mixed with other coniferous species. The undergrowth generally consisted of perennial bunchgrasses with relatively few shrubs, principally big sagebrush (Artemisia tridentata var. vaseyana) and bitterbrush (Purshia tridentata). Low intensity ground fires were frequent enough to maintain most of the stands in an open "parklike" condition. Alteration of eastside pine stands by European settlers commenced in the 1880's with intensive logging, fire suppression, and livestock grazing, and these activities continued to increase after World War I. As a result, the eastside pine plant communities have been substantially altered. Eastside pine stands today are more densely stocked with smaller diameter trees. Canopy values for trees and some shrubs are greater. At higher, moister elevations, California white fir (Abies concolor var. lowiana) encroaches on eastside pine, whereas on lower, drier sites, western juniper (Juniperus occidentalis) invades pine stands.

INTRODUCTION

Characterized by Jeffrey and ponderosa pine forests, the eastside pine region in California lies at elevations between 4,000 and 6,500 ft. east of the Sierra Nevada-Cascade crest (McDonald 1983, Fitzhugh 1988). Eastside pine stands are generally dominated by ponderosa (Pinus ponderosa) or Jeffrey (P. jeffreyi) pines, with lesser acreages dominated by Washoe pine (P. washoensis). Associated tree species include California white fir (Abies concolor var. lowiana), western juniper (Juniperus occidentalis var. occidentalis), and lodgepole (P. contorta) and sugar (P. lambertiana) pines (McDonald 1983, Fitzhugh 1988). A variety of young trees, shrubs, and grasses can be found in the undergrowth.

Eastside pine has been extensively altered since settlement of the eastside pine region in California by emigrants from Oregon and the eastern United States (Pease 1965). Timber harvest practices plus other resource uses, such as grazing of domestic livestock and fire suppression, have combined to alter the presettlement composition and structure of the eastside pine forest. Although some of these changes have been documented, impacts of these activities on coniferous forests in northeastern California are not well known (Rundel et al.

[1] Paper presented at the Multiresource Management of Ponderosa Pine Forests Conference. [Flagstaff, Arizona, November 14-16, 1989].

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1977). This paper describes the composition and structure of eastside pine at the beginning of the settlement period (about 1850), the major demands on eastside pine and associated vegetation, how eastside pine changed through time, and the current composition and structure of eastside pine stands.

STUDY AREA AND METHODS

Our study area is the northeastern corner of California, including all or most of Modoc and Lassen Counties, and the eastern portions of Siskiyou and Shasta Counties (fig. 1). Historical information for the study area on presettlement composition and structure of eastside pine, and on the activities that altered it, was collected from journals from the fur-trapping, emigrant, and settlement periods; histories of specific geographic areas; historical photographic files; and other sources. Where available and appropriate, information from pine forests in adjacent areas, such as Oregon, was used. Information on current composition and structure of eastside pine was taken from three sources: current forest land management planning data bases, and

Figure 1.--The eastside pine study area is indicated by the rectangle bordered by dashed and solid lines. Areas filled by parallel lines indicate the distribution of eastside pine in California (Fitzhugh 1988).

data from the eastside pine ecological classification work and the ongoing investigations of the relationship of birds to snag densities in eastside pine.

RESULTS

Presettlement Eastside Pine

Historical Accounts

Several accounts, from the mid- to late 1800's, provide tantalizing clues of the appearance of eastside pine before settlement. Unfortunately, these reports include little quantification of the composition or structure of the forest. Bidwell (1964), a member of a very early wagon train to California, reported on the characteristics of eastside pine between Walker Lake and the crest of the Sierra Nevada. On 17 October 1841, Bidwell commented that they "passed down and up thro' forests of pine, fir, cedar &c; many of the pines were 12 ft. in diameter and no less than 200 ft. high." On 18 October 1841, when his party was just east of the crest of the Sierra Nevada, he noted that "cedars of uncommon size, pines, the most thrifty, clothed the mountains (one pine, as it was near our camp, was measured. Though it was far from being the tallest, it was 206 ft. high.)"

Hastings (1932), in his promotional guide to Oregon and California, noted that the California mountains have "a great abundance of good timber" (Hastings 1932: 71). Virgil K. Pringle, a member of an emigrant train, reported on 20 September 1846, in the vicinity of Fandango Pass in the Warner Mountains, that their camp was "in a beautiful plain surrounded by stately pine and cedar" (Helfrich 1971: 63). Bryant (1985), part of an emigrant train traveling along the Truckee River, noted on 23 August 1846 that he "passed several yellow-pine trees in the bottom, of large dimensions, the trunk of one of them measuring eighteen feet in circumference"..."in front of us, to the west, there is an elevated range of densely timbered mountains." Again, on 24 August, Bryant observed that "mountains are covered with a thick growth of tall and symmetrical timber. Among the varieties of trees I noted the yellow and white-pine, the fir, the common red cedar, and the Chinese arbor vitae. Many of the firs and cedars are 200 feet in height, with a diameter at the trunk of six or eight feet, beautifully tapering to a point."

Howell, a member of an emigrant train passing through Fandango Valley on 4 July 1849, recorded that there was "heavy pine timber" (Helfrich 1971: 68). Bruff (1949) noted in his diary, while crossing the Warner Mountains on 30 September 1849, that there was large timber on the mountain ahead (Warner Mountains), and after he had reached the top of the pass and begun the western descent, on 3 October 1849, he recorded that the hills were "thickly timbered with firs and other kinds of tall pine trees."

On 10 October 1849, Bruff observed, probably in the vicinity of Adin Pass, that there were numerous oaks among pines.

Beeson, on 19 August 1853 in Fletcher Creek Canyon, noted in his diary that the canyon was rough and rocky and contained a great deal of timber (Helfrich 1971: 76). Mrs. P. S. Terwilliger describes eastside pine forests at several locations along the Applegate Emigrant Trail. On 28 September 1854, while her emigrant train was in the Warner Mountains, she noted that they camped on the "edge of great pine wood" (Helfrich 1971: 68). On 29 September 1854, she described Fandango Valley as having "some fine timber" (Helfrich 1971: 69). Later, on 2 October 1854 along Fletcher Creek on Devil's Garden, Mrs. Terwilliger observed "Plenty of pine wood" (Helfrich 1971: 76). Fariss and Smith (1974), in their history of counties in northeastern California, reported that the growth of conifer trees, along the western border of Lassen County, was sufficient to produce millions of board feet of the best quality timber annually.

Stand Structure of Presettlement Eastside Pine

Although early historical accounts give clues to the appearance of eastside pine, they do not provide a clear view of the characteristics of presettlement eastside pine. Examination of forestry reports from the turn of the century, historic photographs depicting eastside pine and various logging scenes, and present-day photographs of eastside pine stands that have not been substantially altered provides more detailed information about the composition and structure of eastside pine forests. There is little doubt that eastside pine forests were highly variable in structure and composition (figs. 2, 3) (Burcham 1959, Moir and Dieterich 1988). However, now we do not have information to describe these variations. Structure and composition of ponderosa pine

Figure 2.--Eastside pine stand in the western part of the Modoc National Forest, California, about 1930 (USDA Forest Service photograph).

Figure 3.--Eastside pine forest near Happy Camp Guard Station, California, about 1930 (USDA Forest Service photograph).

forests in California were generally related to the availability of soil moisture in summer and fire history (Rundel et al. 1977).

Before settlement, eastside pine generally consisted of either monotypic stands or mixtures of ponderosa and Jeffrey pines. Pine stands also existed as mixtures with other conifers, especially with California white fir; both sugar pine and incense cedar (Libocedrus decurrens) were infrequent associates (Berry 1917). Other tree species found in association with ponderosa and Jeffrey pine included Washoe, lodgepole, and western white (Pinus monticola) pines, red fir (Abies magnifica), Douglas-fir (Pseudotsuga menziesii), western juniper, and California black oak (Quercus kelloggii) (Smith et al. 1988). Distribution of trees varied from scattered patches of trees to virtually continuous stands (Pease 1965).

Structurally, eastside pine was generally composed of large trees that were widely scattered. Canopy closures tended to be relatively low, probably ranging from about 30 percent on dry sites to 80 percent in the most productive areas (Smith et al. 1988). Berry (1917) reported that yellow or Jeffrey pine trees are often only four-log trees (a standard log was 16 ft. long), suggesting that mature trees generally were shorter than 100 ft. Stands of ponderosa pine in Oregon consisted of small groups of trees of similar ages; however, the groups varied greatly in age (Munger 1917, Franklin and Dyrness 1973).

Munger (1917) reported that fully stocked stands had from 20 to 30 trees (> 12 in. diameter) to the acre; however, densities were highly variable. Basal areas ranged from 56 to 100 ft.^{2} per acre, and quadratic mean diameters (qmd) ranged from 16 to 27 in. diameter at breast height (dbh). Volume per acre was also highly variable. Berry (1917)

noted that the average volume of eastside pine was 11,000 board feet per acre, and Munger (1917) published values of volumes, ranging from 14,000 to 25,000 board feet per acre.

Undergrowth vegetation was principally composed of perennial bunchgrasses with lesser amounts of shrubs especially where the canopy was more open. Then, as now, Idaho fescue (Festuca idahoensis) was the most abundant of the bunchgrasses at some sites. Lesser amounts of bluebunch wheatgrass (Agropyron spicatum), Sandberg bluegrass (Poa sandbergii), squirreltail (Sitanion hystrix), and Ross's sedge (Carex rossii) were often present. Common graminoids in moister ecological types were Wheeler bluegrass (Poa nervosa) and needlegrasses (Stipa sp.).

Common shrubs included mountain big sagebrush (Artemisia tridentata var. vaseyana), rabbitbrush (Chrysothamnus nauseosus), bitterbrush (Purshia tridentata) (Pease 1965), mountain mahogany (Cercocarpus ledifolius), pallid serviceberry (Amelanchier pallida), rabbitbrush goldenweed (Happlopappus bloomeri), greenleaf manzanita (Arctostaphylos patula), pinemat manzanita (Arctostaphylos nevadensis), snowbrush (Ceanothus velutinus), and squaw-carpet (Ceanothus prostratus) (Applegate 1938, Smith et al. 1988).

Applegate (1938) noted that bitterbrush was practically the only shrub found in some areas of eastside pine. Smith (1989) provided information on the potential canopy structure of presettlement eastside pine based on an evaluation of existing, but relatively unaltered stands; most of the stands examined, however, had not been burned in 60 to 70 years. Smith concluded that shrub cover exceeded 10 percent where overstory canopy closures ranged from 35 to 55 percent, whereas shrub cover was less than 10 percent where tree canopy cover averaged about 65 percent.

Eastside pine ranged over elevational and latitudinal gradients; on the edges of its range, areas of transition with adjacent plant communities existed. At higher and moister sites, eastside pine graded into mixed conifer with species such as California white fir and incense cedar, whereas at lower and drier sites, pines became mixed with western junipers, especially on rocky sites.

Activities Influencing Eastside Pine Forests

Settlement of Northeastern California

Several groups of American Indians inhabited the eastside pine region in northeastern California when settlement was initiated about 1850. Brown (1945) stated that the presettlement Indian population may have been equal to or even exceeded the combined Indian and non-indian population of the area in 1945. One of the major impacts of Indians on the land may well have been their use of fire to deliberately burn off the grass and shrub vegetation (see the section entitled Wildfire and Its Suppression for a discussion of the use of fire by American Indians).

The first visitors of European extraction to the eastside pine area of northeastern California included fur trappers, livestock drovers, and military explorers. Fur trappers entered the study area first around 1828 or 1829 and followed the Pit River in their travels between the Hudson Bay Company trading posts in the Pacific Northwest and the Sacramento Valley (Brown 1945, Pease 1965). Apparently they trapped while traveling through the region. They did not, however, collect many furs. In 1834, Ewing Young drove livestock purchased in northern California north into Oregon across the western portion of the eastside pine region (Pease 1965).

U.S. military explorations of the area began in 1841 when Charles Wilkes passed by the Pit River as his party traveled between the Columbia River and San Francisco Bay. John Charles Fremont may have entered Surprise Valley during his travels in the area in 1843. The first description of the eastside pine region that included specific details was written by Fremont who, in 1846, mapped and named topographic features in the vicinity of Tule Lake (Brown 1945). Later explorations by W. H. Warner and R. S. Williamson in 1849 and two of the 1854 Pacific Railroad Explorations (led by E. G. Beckwith to the south of the Warner Mountains and R. S. Williamson and H. L. Abbot to the north of the Pit River and beyond Klamath Lake) provided much needed information about northeastern California.

The earliest emigrant trails to Oregon were difficult for pioneer travelers (fig. 4). In search of an easier route, the Scott-Applegate party in 1846 explored a trail from southern Oregon that intersected the California trail along the Humboldt River in northwestern Nevada (Brown 1945, Pease 1965). Emigrant trains to Oregon and California, beginning in late 1846, passed through northeastern California using the Applegate Trail and later, the Lassen and Nobles trails. Most of these travelers crossed the Warner Mountains using Fandango Pass and then moved down the Pit River (Lassen Trail) or crossed farther to the south from Honey Lake and then to the north of Mt. Lassen (Nobles Trail).

Development of the study area began in the late 1850's with the establishment of settlements in the Fall River and Honey Lake valleys. Surprise Valley was first settled in the early 1860's. Growth of the area was rather slow. The population of Modoc County grew slowly from 4,399 (1880), 6,191 (1910), 8,713 (1940), 9,678 (1950), 8,303 (1960) (Pease 1965), to 8,425 in 1980. The economy of the area depended largely on agriculture until about 1920, when increasing amounts of finished lumber

and saw logs began to be exported from the local area, and the importance of timber production to the local economy substantially increased (Pease 1965).

Transportation systems developed slowly in northeastern California (fig. 5). Initially, transportation was by wagon over primitive roads, some of which followed the early emigrant trails. In 1881, the predecessor to the Nevada-California-Oregon (NCO) Railway initiated construction of a narrow gauge line to the Columbia River from Reno, Nevada. Honey Lake was reached in 1890, and construction ceased for some 10 years because funding for construction was not available. Alturas was finally reached in 1908 and Lakeview, Oregon, the terminous, in 1912 (Myrick 1962, Barry 1982). This railroad accessed only the eastern edge of the study area.

The rail network in northeastern California was developed more fully in the 1920's and 1930's. By 1930, the Southern Pacific Company had widened the old NCO Reno-to-Lakeview line to standard gauge and constructed a new line from Alturas to Klamath Falls, Oregon. In 1931, the Great Northern Railway line from Klamath Falls and the Western Pacific Railroad branch from Feather River canyon met near Bieber. The rail transportation network was completed with the addition of numerous logging railroads. One was

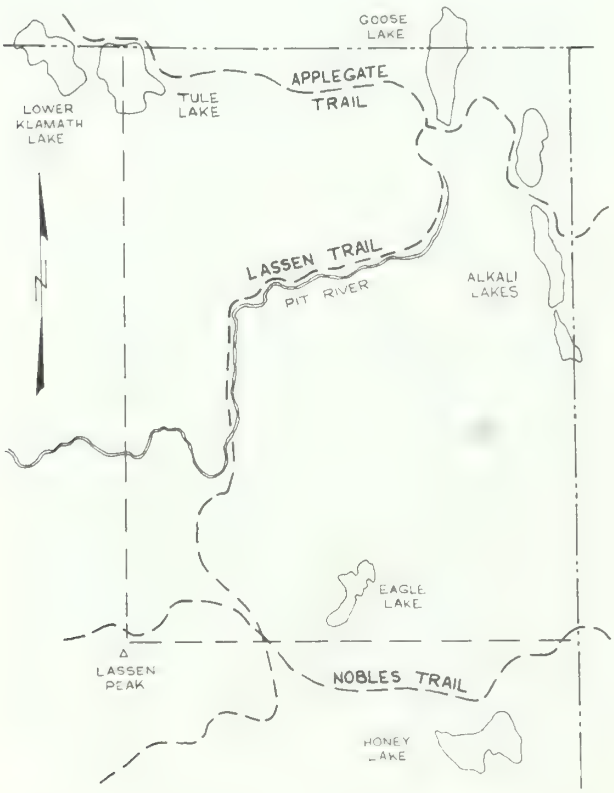

Figure 4.--The eastside pine study area indicating the Applegate, Lassen, and Nobles emigrant trails.

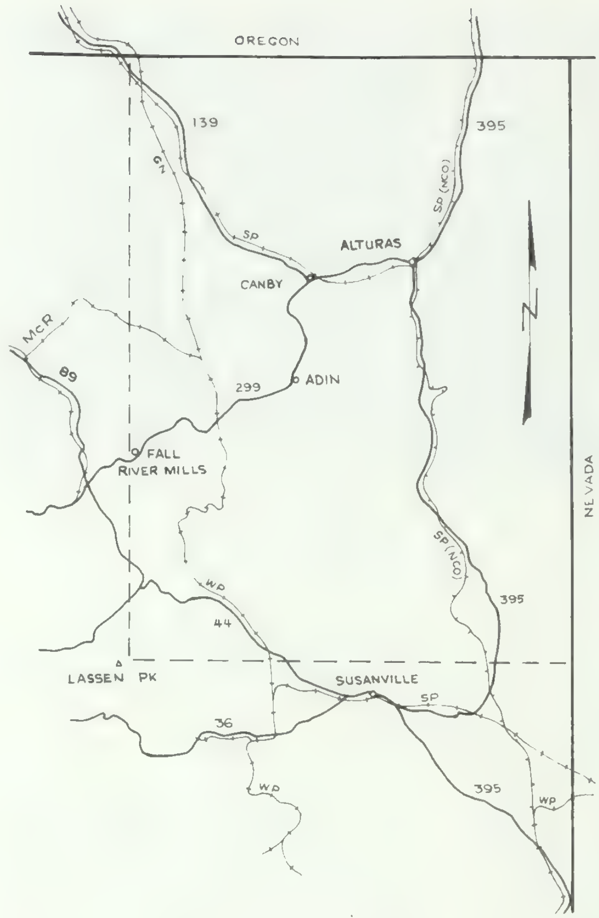

Figure 5.--The eastside pine study area indicating major towns, common-carrier railroads, and major highways. Common-carrier railroads are: GN = Great Northern (now Burlington Northern), SP (NCO) = Nevada-California-Oregon (now Southern Pacific), McR = McCloud River, SP = Southern Pacific, and WP = Western Pacific. Major highways are: 36 = Calif. 36, 44 = Calif. 44, 89 = Calif. 89, 139 = Calif. 139, 299 = Calif. 299, and 395 = U.S. 395.

the Long-Bell Lumber Company whose main extended from near the Pit River north of Lookout to the Southern Pacific mainline at Weed (Myrick 1962, Shoup and Baker 1987). Another was the McCloud River Railroad connecting the areas around Whitehorse and Burney with the Southern Pacific near McCloud. Others were the Great Northern near Lookout (Myrick 1962, Hanft 1971), the Red River Railroad with an electrified main line in the Chester/Westwood area (Myrick 1962, Hanft 1980), and other logging lines extending into the woods from connections with the Western Pacific (Myrick 1962).

Highways for motorized traffic have also played an important part in the recent development of the area. Early roads followed the emigrant trails or were constructed to

connect early towns (fig. 4). Two-lane federal and state highways access most major towns in the study area, and additional county and forest roads provide access to the rural areas (fig. 5).

Timber Harvest

Timber harvesting, from the initial settlers on, was an important activity in northeastern California. Wood was harvested for boards and shingles to construct dwellings, barns, and other structures. Initially, structures were built of logs. However, within a very short time, mills were established and pine boards and shingles became the preferred building materials. Fuelwood was used for heating, cooking, and fueling steam-powered equipment. Other wood products from eastside pine include timbers and planks for use in the mines, water ditches, and railroads (Berry 1917, Pease 1965), and box shook, coffin material, and sash and door stock.

Initially, timber products were taken from forests close to centers of development. In 1880, three mills were operating in the Warner Mountains to supply wood products to Surprise Valley and a fourth mill served the Alturas area. Early mills were water powered and were located in canyons to utilize water power resources. The mills were quite small and were situated close to the timber to be cut and the community to be served because of the lack of adequate transportation. By 1912, 5 million board feet of lumber was harvested yearly to satisfy local demand.

Beginning about 1920, mills increased in size and began to export timber to areas outside the eastside pine region. Finally, by 1935, the timber industry generally became economically dependent on export sales. Consequently, mills became even larger, to exploit the relatively large sales of timber or the large expanses of private timberlands that were then owned by only a few companies. By 1940, nine mills in Modoc County produced 107 million board feet of lumber. A similar amount of lumber was produced by mills in Siskiyou County, California, or at nearby mills in Oregon from saw logs harvested in Modoc County. By 1963, only 78 million board feet of lumber were exported from four mills in Modoc County (Pease 1965). Currently, some 20 million board feet of lumber are milled each year in Modoc County.

Timber stocks have declined substantially since the 1930's. By 1934, 52,250 acres of timberland in Modoc County had been cut over. The total number of acres that had been harvested reached 136,750 acres by the end of 1938 and 259,750 acres by the end of 1943 (Brown 1945). At present, virtually all of the virgin timber has already been harvested, and cutting is taking place in stands that had been cut over earlier in this century.

Harvest practices varied through time and depended, to some extent, on the landowner. Generally, only merchantable trees were harvested. Logging and market conditions varied considerably and, therefore, the definition of merchantability varied in time and from place to place (Berry 1917). Those trees not considered merchantable, because the species was not desired or the wood was defective, generally were not cut. Only about 5 percent of ponderosa pine generally was defective (Berry 1917). Preferred species for harvest were, and still are, pines; recently, California white fir has become a more important component of the timber supply (Pease 1965).

The sizes of trees left after harvest depended on the tree species found on the site. Pines with diameters inside the bark of greater than 14 to 15 in. were usually harvested. Some companies took all trees that met the appropriate size criteria, whereas other companies harvested only pines and the best of the firs and incense cedars (Berry 1917). As an example, USDA Forest Service reports supporting the transfer of cutover eastside pine lands from the Long Bell Lumber Company to the Forest Service documented that California white fir and incense cedar generally remained after harvest and, on some sites, a residual overstory of pine was left[4]. In more recent years, overstory removal of only the largest trees has become more common.

Stumps from 16 to 36 in. in height usually remained after harvest (Berry 1917). High stumps were left because the lowest portions of the trees were commonly defective from fire scarring or accumulation of pitch from low intensity burns.

Livestock and Range Management

Early livestock operators concentrated on raising cattle along the meadow lands of the Pit River. Livestock production, during the years immediately after settlement, was for local consumption, and excess production was added to the herds. By 1910, the livestock industry had increased substantially.

In 1880 there were 16,000 beef cattle, 23,000 resident sheep, and 6,000 horses in Modoc County. In 1909, there were 44,000 beef cattle, 76,500 resident sheep, and 15,000 horses (Pease 1965). By this time, livestock operations had come to depend on the adjacent uplands for summer graze so that the meadows in the vicinity of the Pit River and its tributaries could be used for production of hay for winter feed and cash crops. About 1880, sheep drovers from the Sacramento Valley, Nevada, and Oregon began to

[4] Goldsmith, B. C. 1933. unpublished land valuation reports [on file at Klamath National Forest Supervisors Office, Yreka, Calif.]

graze large transient flocks in eastside pine forests and on the adjacent grasslands.

Intensive, unmanaged grazing of the eastside pine forests and adjacent rangelands resulted in the decline of perennial bunchgrasses and increase of the invasive cheatgrass (Bromus tectorum) as well as shrubs and small trees. At the time of the first settlements in the area, extensive acreages of bunchgrass had little or no junipers or sagebrush. However, junipers and sagebrush increased substantially in the period during and after unmanaged grazing, especially of sheep (Caldwell 1985). The increase in woody vegetation is also related to fire exclusion, and the removal of fine fuels by livestock.

Controls were placed on the numbers of animals grazed and on grazing practices after establishment of the Forest Reserves (1904) and the Grazing Service of the U.S. Department of Interior (1935) (Brown 1945). These controls have resulted in an improvement in some areas since then. In the absence of fire, lower, more xeric stands of eastside pine and vast acreages of adjacent rangeland are being invaded by western juniper, causing serious deterioration of range condition in many areas.

Wildfire and Its Suppression

Fires, both natural and human-caused, have affected structure and composition of eastside pine in California. Ponderosa and Jeffrey pine are resistant to fire because of a thick, dead layer of outer bark even at small diameters. Other species, such as California white fir, do not develop this thickened bark and are more easily killed by the lowest intensity ground fires (Hall 1977).

Lightning-caused fires are frequent in the study area. The Modoc National Forest has recorded over 5,000 lightning-caused ignitions since 1913 (Elizabeth Cavasso, personal communication). Under presettlement conditions, fires generally do not appear to have been catastrophic but occurred frequently enough to reduce the undergrowth trees and shrubs substantially. Franklin and Dyrness (1973) reported that fire intervals in ponderosa pine in Oregon ranged from 8 to 20 years. These fires generally were of low intensity and were confined to the ground.

Fire can substantially reduce shrub cover and increase grass cover especially on more xeric sites. Fires before settlement regulated regeneration of pine and resulted in open, grassy, parklike stands (Franklin and Dyrness 1973). Munger (1917) noted that western yellow pine (= ponderosa pine) was fire resistant because destructive crown fires in the typically open stands were rare; most fires were confined to the surface consuming grass, needles, and shrubs. Ground fires also caused damage to stands by directly killing a few trees, and scarring the butts of merchantable trees (Munger 1917).

The effects of fires set by native Americans in northeastern California are not well understood. Bean and Lawton (1973:v) stated that "burning was the most significant environmental manipulation employed by California Indians." Burcham (1959) concluded that fire was used by Indians to aid in hunting in northeastern California. Indians used fire in northeastern California to aid in hunting animals and improve wild seed crops (Lewis 1973). Lewis also reported that Indians in the lower Pit River Valley burned mixed chaparral in the spring; however, he did not postulate an objective for burning. Pease (1965) concluded that extensive burning would probably not improve habitat quality and animal numbers and, therefore, it is not likely that extensive planned burns took place. It is likely that Indians used fire to alter the vegetation for hunting and gathering purposes. It is not clear to what extent, either in frequency or area of extent, fire was used in our study area.

Fires appear to have increased through time both in severity and extent (Brown 1945). Kinney (1900) commented that it was customary to exaggerate the amount of damage done by fire and that "The majority of forest fires in California do not destroy the forests they traverse. Damage is done and much waste takes place, especially in territory long protected" (Kinney 1900:54).

Brown (1945) noted that in the late 1800's, newspapers in northeastern California made only casual mention of wildfires. Occasionally, property owners did group together and fight those fires that threatened their properties. Increased logging operations resulted in the increase of slash and fire hazards. Invasion of eastside pine lands by cheatgrass, and increase of woody shrubs, dense thickets of young trees, and accretion of woody debris have increased the probability of catastrophic fires.

Presettlement vs. Current Stand Conditions

Comparing presettlement and current characteristics of eastside pine is difficult because of the paucity of information available. Munger (1917) described three stands of eastside pine from central and south-central Oregon; we surmised from their locations that the stands were analogous to eastside pine stands in northeastern California. Munger's data imply that these stands were in an unmanaged state, and that they possibly exhibited "old-growth" conditions.

The stands in Oregon had quadratic mean diameters that ranged from 16.2 to 27.1 in. dbh. Basal areas ranged from 54 to 125 $ft.^2$ per acre. Trees per acre for all species ranged from 13.9 to 76.7. The number of trees per acre

with diameters greater than 25 in. ranged from 18 to 64 percent of the total. The number of trees per acre with diameters greater than 30 in. ranged from 9 to 39 percent of the total (Munger 1917).

In contrast, later seral stage stands, currently occurring in northeastern California, have qmd's that range from 17.9 to 21.8 in. dbh, and basal areas that range from 122 to 159 $ft.^2$ per acre. Trees per acre range from 74 to 101. The number of trees per acre with diameters greater than 24 in. range from 5 to 22 percent of the total, and the number of trees per acre with diameters greater than 30 in. range from 2 to 9 percent (Smith 1989).

Comparisons between the current and presettlement characteristics of eastside pine forests reveal the following patterns:

- The regional extent of pure eastside pine stands is smaller. Many acres of stands that were maintained by periodic fire have converted in its absence to "eastside mixed conifer" stands of Jeffrey or ponderosa pine mixed with California white fir, western juniper, or lodgepole pine.

- Eastside pine forests today have greater numbers of smaller trees per acre. Larger, older trees (when present at all) make up a much smaller component of each stand. Average stand ages are less, and tree spacings are smaller. Average stand height is less. Tree canopy closure is higher.

- The amount of herbaceous vegetation is lower. Shrub canopy closure is higher in some types. Shrub stands, especially bitterbrush stands, are more decadent.

- The amount of dead and down material is higher. Litter and duff depths are greater. Some data suggest that presettlement stands, with frequent fires, had fewer available nutrients than current stands that have larger amounts of debris and litter (William Hopkins, personal communication) Available water holding capacity may be higher now because of accumulations of litter and duff.

- Susceptibility to high intensity fires is higher because of the fuel buildups and higher stocking. The likelihood of pine forests escaping stand-destroying fires within the 175-226 years necessary for developing old-growth characteristics is low (Moir and Dieterich 1988, Smith 1989).

- Potential for total numbers of snags is higher now, but numbers of snags, especially those with dbh's greater than 15 in. and heights greater than 20 ft., are low because of aggressive snag-removal programs conducted on National Forests since the 1920's and the reduced numbers of larger trees.

- Susceptibility to disease and insects is probably greater because of the amount of stress that is on the trees. Stress is often related to stocking levels; the greater the stocking, the greater potential for stress.

CONCLUSIONS

Timber harvest, livestock grazing, and change in fire frequency all have had a substantial effect on both the overstory and undergrowth of eastside pine. Timber harvest has removed many of the large trees and, because pines, such as ponderosa, Jeffrey, and sugar, were desired harvest species, timber harvest has reduced them relative to California white fir and western juniper. Structure of pine stands has also changed. The lack of fire has permitted the establishment of denser thickets of small trees, especially California white fir, in the undergrowth. Juniper has replaced the grass/shrub vegetation on large acreages at the lowest elevational margins of the eastside pine type as a result of livestock grazing and fire suppression. Shrubs have increased at the expense of both the grass/shrub vegetation and the grass undergrowth as well.

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Some Observations Regarding Growth and Yield of Southwestern Ponderosa Pine and Dendro-Ecological Growth Studies[1]

Charles E. Thomas[2]

Abstract. New politically provocative problems face the forest manager, acid rain, ozone pollutants and global greenhouse effects potentially impact the growth and health of forests. Long term growth records are becoming increasingly important to understanding tree and stand growth trends under changing environmental conditions. Growth and yield studies in Southwest ponderosa pine began with the pioneering work of G. A. Pearson at Fort Valley. A. E. Douglass pioneered the analysis of growth from studying tree-rings in the Southwest's ponderosa. Analyses of dendrochronological data have undergone recent statistical improvement with the incorporation of extensive computer editing and Kalman filter algorithms.

Long-term growth and yield plot installations, dendrochronologies establishing truly long-term growth patterns, mathematical sophistication and statistical consistency must be brought together, if we are to understand management implications for growth of southwestern ponderosa pine in the future human-influenced environment.

INTRODUCTION

There is currently a debate raging over the impact of human made pollutants on forest health. Studies indicate apparent growth (health) declines in forests of North America and Europe. The techniques to investigate these declines are in rapid development; several approaches have proven fruitful. Some of these declines have been well documented with long tree-ring chronologies (see references in Van Deusen In Press). In other areas, however, purported declines have been based on periodic remeasurement of inventory plots. Initially, these latter 'declines' failed to account for climate factors, but were based instead on a simple comparison of growth rates for two periods. Atmospheric pollution ozone or other anthropogenic causes have received a large portion of the attention in the attempt to assign blame or cause for what remain apparent declines.

Ponderosa pine (Pinus ponderosa) has proven to be one of the species that is affected by at least one specific air pollutant, ozone. In the San Bernardino Mountains and Southern Sierras of California documented effects of ozone on growth and/or growth related physiological features of ponderosa have been reported (Miller et al. 1978). The pollutants that have been identified as causal agents in California have been detected in Arizona and New Mexico. Although the levels are generally lower, there are exceptions. SOx has major point sources and other pollutants are locally important. Mining smelters are the sources of some of the pollutants in Arizona and New Mexico, but automobiles, power plants and other urban sources may also be involved. Air sampling stations established as part of NAPAP (National Air Pollution Assessment Program) near Flagstaff, Prescott, Springerville, and Tucson became part of a data base analyzed by Böhm (1989) that showed some pollutant gases occasionally near chronic levels at more northerly

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sites, while even higher levels occurred at more southerly sites.

One of the research questions posed by the joint USDA Forest Service and EPA Forest Response Program is: "Are changes in forest condition greater than can be attributed to typical trends and levels of natural variability?" The prerequisite for answering this question is that trends and their variability can be quantified. Guessing at a decline in growth will not do.

The past often holds important information for the future, if we are willing to learn from the processes or substance of the past and refuse to let appearances deceive us. In this paper, I will look at some of the historical research into tree growth and explore some of the current efforts to quantify possible anthropogenic pollutant impacts or potential impacts on forest growth that might be useful in the future growth of southwestern ponderosa.

DENDROCHRONOLOGY AND FOREST GROWTH

Arizona is rich in history of the development of two research areas that are of importance to the future management of ponderosa pine for health and timber growth. The pioneering research in forest growth and yield by G. A. Pearson of the US Forest Service on ponderosa pine still provides a resource for those who wish to manage the type for all the multiple resources available from the forest. Pearson's research culminated in 1950 with the publication of *Agriculture Monograph No. 6*, *Management of ponderosa pine in the southwest*. At nearly the same time in history, A. E. Douglass at the University of Arizona was outlining the principles of dendrochronology: *Climatic Cycles and Tree Growth* appeared in 1919. The two scientists were not linked directly as far as I can tell, but Pearson cooperated with W. S. Glock, a protege of Douglass, in the publication of *Principles and Methods of Tree-Ring Analysis* in 1937.

Development of Dendrochronology

In *Principles and Methods of Tree-Ring Analysis*, the methods developed over the years by Douglass for sampling trees, identifying a variety of ring problems and types, measuring the rings, precisely dating individual rings and trees to climate events such as droughts of specific years and duration are illustrated. Missing and partial ring formation are shown to be suitably accounted for by the methods developed by Douglass. Dendrochronology grew up in arid country, and not under the normal forest-stand, inter-tree competition conditions. It has become increasingly important to be able to examine the long-term growth records available not only in the tree-ring chronologies, but also to be able to understand the effects that forest stand dynamics have on observed patterns in the chronology.

H. C. Fritts (1976) also contributed significantly to the development of tree-ring applications and methods. Improved statistical analyses and measuring techniques were added to earlier methods. Dendrochronologists have come to use a number of techniques for analyzing measurements of tree-ring widths that introduce at least two elements that are disturbing to the statistician. First, there is the **uniformitarian** assumption. This assumption states that current stand conditions are analogues for past conditions. In fact, competition status fluctuations that are part of stand dynamics may vary with the environmental changes. Second there has always been a subjective component to the treatment of tree-ring analyses. The two notable components of this treatment are the **subjective smoothing** of long-term record and the statistical **"pre-whitening"**' of the data. While the methods used have sought to follow statistically sound procedures developed for time-series analyses, they continue to rely heavily on a subjective aggregation of methods.

New methods have been developed to provide for time varying parameters and compensate somewhat for the two problems. These new methods will be discussed later.

A recent example of the current application of the traditional dendrochronological method, which relates directly to the concern for atmospheric pollutant and climate influences, is D. A. Graybill and M.R. Rose (1989 in press). These analyses might better be termed dendro-ecological as their principal objective is the influence of the environment on growth rates of forest stands. Analyses of growth trends in conifers for Arizona and New Mexico is presented in a study that was jointly initiated by the FS/EPA.

In the initial stages, several stands were identified as having un-datable periods in the last 30 to 60 years, since up to 40 rings were absent from the chronology. This ring anomaly was totally unexpected because precipitation trends throughout the region show a decline from early in the century reaching a minimum in the '50s and a substantial recovery in the '70s and '80s. Most trees that grew on or above the Mogollon rim demonstrated a "u"-shaped growth curve from the beginning of the century until the present. Trees growing in the Basin and Range region, i.e., south of the Mogollon Rim, from six of seven stands showed no recovery from the period of drought in the '50s.

Regardless of the objections foresters and statisticians have against dendrochronology, the success at determining climatic changes over the past have been truly remarkable. So successful has the science been that it has been used to provide a calibration to the well known carbon-14 dating methods. Recent statistical developments may provide an even richer future for dendro-ecology.

Forest Dynamics and Growth and Yield

Obviously, I'll not cover all the developments in growth and yield, only a brief indication of two historical contributions. Growth and yield studies have long shown that volume increment may not slow in direct relation to basal area or radial growth; it may simply retreat up the bole to the base of the live crown. Therefore, an orderly decline in radial growth of trees or stands occurs while volume growth continues unabated. G. A. Pearson's contribution, **Factors Influencing the Growth of Trees**, to *Principles and Methods of Tree-Ring Analysis* (in Glock 1937) pointed out that tree growth is determined by a large number of factors, some working in conjunction with, others in opposition to each other. Pearson described a number of physical and biotic factors and their interrelationships, which foresters recognize influence tree growth. His conclusion reiterated that volume of wood increment is the only true measure of growth. He emphasized the geometric relationships that must mathematically relate diameter growth to volume growth. He pointed out that vigorous young trees may actually maintain a constant ring thickness even as the diameter of the tree increases, but inexorably the increasing diameter (and in a sense height) of the bole causes a reduction in ring width even if volume growth rate is maintained. As competition and climate factors are encountered over the life span of the tree, the thickness of the ring must decline. These relationships must be accounted for in the analysis of rings between and within trees. The problems with dendrological studies, which the forester Pearson hinted at in this contribution, continue to bother many silviculturists and quantitative foresters to this day. Of course, volume increment is much more difficult to obtain than ring-width.

The methods for studying growth and yield have continued to be based primarily on long-term remeasured permanent plots. The value of these plots to growth and yield and to future investigations of environmental change cannot be overestimated. Short term plots may be useful for interim analyses, and may contribute to a data base which consists primarily of long term plots, but they do not of themselves constitute a source worthy of estimating the growth of forest stands. Stem analyses have contributed significantly to our understanding of forest growth and continue to have a role to play, but neither can they be the sole information on stand level growth. In like manner the tree-ring record of radial growth appears to have great potential for contribution to our understanding of growth and yield, but stand-dynamic considerations will probably always require some sort of permanent installation to evaluate growth in any quantitatively serious manner.

As has been noted, foresters interested in the results of stand management experiments did not become involved in dendro-ecological studies, but the following exception provides a well-founded basis for future endeavors. The same year (1937) that Glock's book appeared, F. X. Schumacher and H. A. Meyer published ***Effect of Climate on Timber-Growth Fluctuations***. Schumacher was one of the outstanding quantitative foresters to emerge early in the history of forestry in the United States. While the article seems to have failed to stimulate widespread use of the technique in similar treatment of growth and yield information then, the time may have arrived now for implementation of its inchoate substance. Schumacher and Meyer treated data brought from Switzerland by Meyer, regarding twelve white fir (Abies alba). They had the objectives to (1) partition the variation in annual growth over a 63-year period into within-stand and outside-stand influences and (2) to investigate the effects of climate on timber growth. While the species is foreign and the data over a half century old, I believe it could have relevance for current research in growth and yield for ponderosa.

The authors indicated that a measure of annual growth variation due to climate fluctuation is basic to judgements concerning the efficiency of silvicultural treatment in a regulated forest. Without information on the climate flux, comparison of periodic growth before and after silvicultural treatment may be seriously misleading.

Beginning with simple correlations between sample pairs of trees, which showed very little correlation, and proceeding to correlation between residuals for two groups of six trees that show very high correlations the authors indicate that factors external to the stand contribute the bulk of the variation between the averages of the six trees. The principal factors were most likely weather or climate. Analysis of variance of the same cores indicate that climate accounted for about **93 percent** of the variation external to the individual trees. The amount of growth variation decreases with period length, but the differences are notable for periods commonly used to remeasure permanent sample plots. Table 4 from Schumacher shows the percent coefficient of variation for diameter growth. Treatments which have effects similar in magnitude to the remaining variation would be extremely difficult to demonstrate.

Having identified the culprit in the tree-ring record as climate, Schumacher and Meyer made an effort to establish a method for accounting for the climatic fluctuations when making comparisons of periodic increment. I will not try to cover their results here, partly because I believe newer analysis methods are more appropriate today, but I suggest that interested researchers should consult the original.

Their conclusions need reiteration. Most of our knowledge of growth and yield comes in the form of information from periodic remeasurement of sample plots. Comparisons among treatments for

Table 4. -- Coefficient of variation of periodic diameter growth. (from Schumacher and Meyer (1937)

Period	Deviation from 63-year trend	
	1-std dev	3-std dev
1	15.4	46
5	6.9	21
10	4.9	15
15	4.1	12
20	3.4	10

the purpose of estimating the effect on growth of an applied treatment or an observed catastrophic event is the common method of identifying potential treatments or causes of unusual events or trends.

The antecedent analyses illustrate clearly that climate fluctuations from year to year affect increment to an extent that might mask or enhance the effect we are investigating in a particular growth period. A method to eliminate the effect of climatic change may be necessary in order to obtain an estimate of the effect that is actually due to the treatment or observed event.

THE KALMAN FILTER FOR TIME VARYING PARAMETERS

Tree-ring analyses began with assumptions that related strongly to the arid southwest. As I have noted some of the assumptions were objectionable to foresters involved in growth and yield because foresters tend to see that individual tree growth changes systematically with stand dynamics regardless of short term climate changes.

P. C. Van deusen and J. Koretz (1988) and Van Deusen (Dynaclim version 2.0, 1989) present a series of tree-ring analysis programs which have rather distinctive properties: 1) there is no requirement for the uniformitarian assumption, 2) all trees are maintained in the chronology as opposed to a single index series; data reduction is obtained by estimating parameters rather than a single mean, and 3) simultaneous estimation of mean and climate model is achieved eliminating the necessity of subjectively fitting a pre-whitening curve.

A state space formulation is developed in Van Deusen and Koretz. The equation of observations is:

$$Y_t = F_t\ a_t + v_t \qquad (1)$$

where Y represents ringwidths, F is a matrix of 1's in column one and 0's elsewhere, a represents the parameter vector to be estimated, v is the error vector and subscript t indicates the number of time intervals in the chronology. The transition equation is given by:

$$a_t = G_t\ a_{t-1} + w_t \qquad (2)$$

where G is a transition matrix and w is the associated error vector. For both error vectors, error matrices (V_t and W_t) exist and can be specified.

These equations can be solved using Kalman filter theory. The Kalman filter is a set of equations that provide estimates of the parameters in equations 1 and 2 that have the general property of being the best linear unbiased estimates when certain assumptions about the error matrices V_t and W_t hold. The error matrices both have mean zero, but are not contemporaneously correlated. Further there should be no serial correlation within or between the two error matrices.

State parameters are estimated in three steps: prediction, update and smoothing equations. The process is complicated, but the idea is relatively simple. The Kalman filter has been around for many years in the electronics industry as a method for removing noise from electronic signals that may be modulated, i.e., deteriorating over time.

The programs developed in DYNACLIM (Van Deusen 1989) allow for the dynamic modeling of climate from tree rings that have statistically sophisticated properties when compared to the more subjective methods that have developed over the years. The comparison of this method with older methods has proven quite favorable. Illustration of the results of sample analyses are presented, briefly. Figure 1 shows the time varying parameter for a Michigan/hemlock series. Figure 2 portrays the actual ring variation for a number of red spruce from White Face Mountain. This new analysis system provides us with a more objective methodology that also appears to have the potential to answer some of the traditional forester's objections to dendro-ecological investigations.

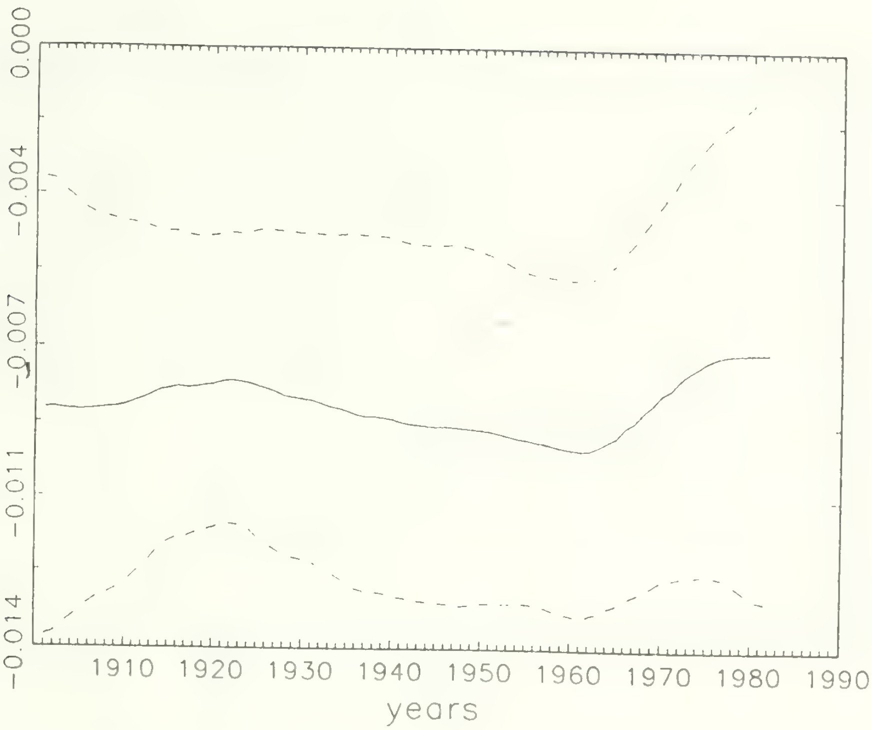

Figure 1.-- Example graph made with Dynaclim module dynaplot, showing time varying parameter and approximate 95% confidence intervals for the parameter. (from Dynaclim version 2.0, Van Deusen 1989)

SUGGESTIONS AND CONCLUSIONS

Foremost among considerations for growth and yield in the management of any forest type must be a serious commitment to long-term permanent plot studies. No serious forest growth program can be conducted with temporary plots alone. Dendro-ecological methods can contribute in several ways to the utility of permanent plots. First, the effect of random temporal correlation between short term climate fluctuation and treatment (or observed condition class) can be reduced, greatly enhancing the scientific and predictive value of permanent plots. Second, the results from permanent plots may be extrapolated to conditions not encountered in the permanent plot installation with somewhat more confidence, if a solution to the forester's objections can be found.

This leads to my conclusions which are highly speculative, but I hope constructive in the long run. First, the management of all forest types is increasingly dependent on long-term accurate appraisals of the growth rates in a changing environment. Changes in the atmospheric environment could have major impact on the growth or health of forests, however, we will never be able to speak knowledgeably about current growth declines if we cannot determine long-term trends. It is unlikely that detailed growth and yield programs such as are being developed for rapidly growing Southern forest tree species types or Pacific Northwest types will ever be constructed for slower growing ponderosa pine type forests. Dendro-ecology in conjunction with existing permanent plot installations may provide a workable growth estimation approach. As we reflect on Schumacher and Meyer's paper, we ought to see that changes in short term climate patterns should not have been ignored by foresters for the past 50 years. Periodic remeasurements should have been corrected for climatic effects as they suggested. Second, foresters shouldn't turn up their noses at the serious contributions that dendrochronologists have made to understanding climate. If there are legitimate forestry condemnations of dendro-ecology, they lie in the inability to reconstruct the mortality of the stand. But perhaps we have simply overlooked some possibilities due to the NIH[3] objection. It is true, dendrochronologists have concentrated on extracting the climate signal by extracting cores from dominant trees. However, it is possible that a stand dynamic signal remains in the tree-ring record in intermediate or suppressed trees. It is likely that the signal would be difficult to extract, but we have new statistical tools with which to examine the records.

[3] Not invented here, NIH.

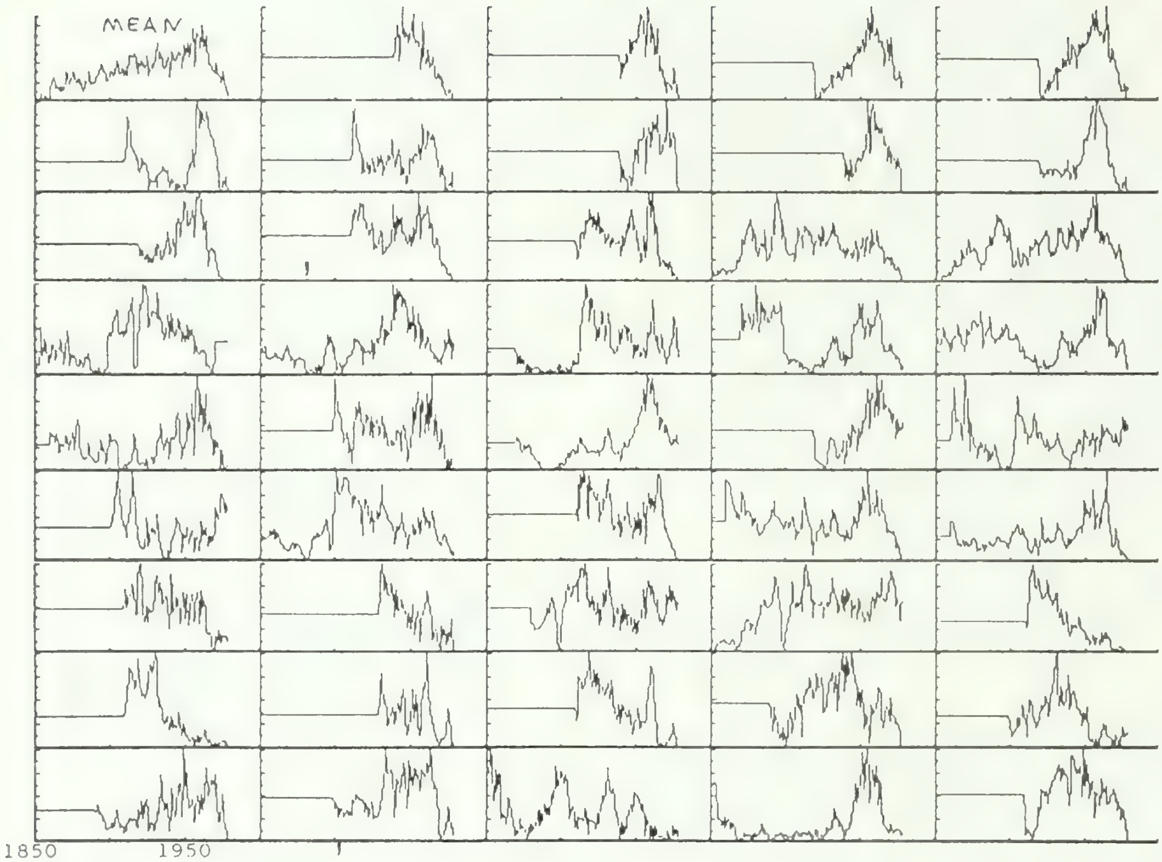

Figure 2.-- Mean tree-ring chronology and 44 individual tree cores from Whiteface Mountain red spruce. Plots extracted from program multiplot of Dynaclim version 2.0 (Van Deusen 1989)

It is up to us now; we need to assemble the tools to study growth in our changing environment, if we hope to explain observed variation in tree growth (health). We will need to use all the knowledge and resources available to us. At a minimum, this means continuing to study periodic growth from permanent plots, supplementing this information with tree-ring record analyses to determine the historical trends and possible shifts in environmental conditions, and applying the latest statistical analysis techniques to detect and identify environmental signals in the development of trees and forest stands.

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A Growth and Yield Parameter Recovery Model for *Pinus cooperii* in Northern Mexico[1]

Celedonio Aguirre Bravo and Susan Winter[2]

Abstract.-- Stand stock tables are estimated for a species closely related genetically and ecologically to Pinus ponderosa using a parameter recovery model to describe the product size class information of the stand. The diameter distributions predicted with the Weibull parameter recovery model are validated with an independent set of data using the Chi-square and Kolmogorov-Smirnov goodness of fit statistics as criteria for comparison. The observed diameter distributions of the validation data were closely approximated with the parameter recovery procedure used in this study.

INTRODUCTION

Stand average and diameter distribution models are the two most common approaches for predicting the growth and yield of forest stands. Stand average models have limited value to forest managers because they do not produce detailed information of the product class size distribution for a particular set of stand conditions. Diameter distribution models, on the other hand, provide a full description of the stand structure in terms of number of trees, mean height, basal area, and volume by diameter class. Models for predicting detailed information about the stand structure are essential to forest management planning.

Different mathematical functions have been used to model diameter distributions in even-aged stands. Evaluation of these probability density functions (pdf) indicate that they differ in flexibility and complexity when fit to diameter distributions (Lenhart 1968), and their cumulative density functions (cdf) may or may not have a closed form solution (Hafley and Schreuder 1977, and Cao 1981). For example, the beta distribution is flexible enough to model diameter distributions, but its cdf does not exist in closed form (Burkhart and Strub 1974). In this case, numerical integration techniques are required in order to determine the proportion of trees in each diameter class.

The Weibull distribution possesses many desirable properties for fitting diameter distributions. Its genesis, properties and applications are described by Johnson and Kotz (1980). An important advantage over the beta distribution is that its cdf has a closed form and is more flexible for modelling diameter distributions of different shapes (Bailey and Dell 1973, Frazier 1981, Clutter et al. 1983). The Johnson's SB distribution (Johnson 1949) has been found to be consistently better than the Weibull. However, in addition to the lack of a closed form expression for its cdf, the use of this function is more complex and involves the prediction of four parameters (Rennolls et al. 1985). The Weibull pdf exists in either a two or three parameter form. The three parameter form has the advantage of providing more flexibility for modelling diameter distributions (Knoebel 1986).

Diameter distribution models based on the Weibull distribution require efficient procedures to determine the parameter estimates of its probability density function. A common approach consists of estimating the Weibull parameters as a function of some average stand attributes (i.e., stand age, site index, and stand density). Other techniques predict the 24th, 63rd, and 93rd percentiles of the weibull pdf from stand average attributes in order to solve for the parameter estimates (Clutter et al. 1983). These methods may result in biased parameter estimates due to the

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low R^2 of the parameter prediction equations (Frazier 1981, Bailey et al. 1981).

Another alternative used to obtain estimates of the parameters of the Weibull pdf is based on the parameter recovery procedure introduced by Hyink (1980). The method consists of estimating the first two noncentral moments of the Weibull pdf from stand average models in order to solve for the parameter estimates. The advantages of this approach are the ability to partition yield by diameter class, mathematical compatibility between stand average models and diameter distribution models, and consistency among the various stand yield estimates (Knoebel 1986). A generalized framework of this technique is given by Hyink and Moser (1983).

The purpose of this study was to develop a parameter recovery growth and yield-based model using temporary plot data from natural even-aged stands of Pinus cooperii (Blanco) from Durango State, Mexico. The parameter recovery procedure of the model is based on the technique described by Burk and Burkhart (1984). An evaluation of the model's accuracy and ability to recover stand diameter distributions was conducted using an independent set of validation data.

DATA

Data for this study were collected from natural even-aged stands of Pinus cooperii at the El Salto Forest Management Unit No. 6 Durango State, Mexico. A sample of 1850 temporary plots of 0.0125 ha were surveyed from 800 stands of a wide range of ages, site indices, and stand density. Plots in each stand were measured for the following information: DBH (cm), tree height (TH; m), 5 and 10-year diameter increment (mm) of dominant - codominant trees, age of dominant and codominant trees (years), crown class dominance, bark thickness (mm), and species. Trees in each plot were tallied to a 2.5 cm DBH limit. Plots having a species mixture higher than 5% were not considered in this study.

Plot data were summarized to generate the following variables on per hectare basis: mean age (A), mean dominant-codominant height (H), mean height per diameter class (HM), quadratic mean diameter (Dq), arithmetic mean diameter (D), minimum observed DBH, current basal area (B), five-year period basal area growth, volume (V), and Reineke (1933) stand density index (SDI). Plots for all these variables indicated a reasonable distribution over a wide range of ages, site indices, and stand densities.

From this data set, a random sample of 70 plots from stands of different ages, site indices, and stand densities was used to validate the performance of the parameter recovery procedure. The remaining plots were utilized for developing growth and yield equations.

PARAMETER RECOVERY PROCEDURE

The three parameter Weibull probability density function (pdf) was used for modelling the diameter distribution of natural even-aged stands of Pinus cooperii. The pdf of the Weibull is given by

(1) $$f(x;a,b,c) = (c/b)*([(x-a/b)^{c-1}]* \{\exp[-(x-a/b)^{c}]\}$$

$a \le 0$
$b, c > 0$
$a < x < \alpha$
0, otherwise

where

a = location parameter
b = scale parameter
c = shape parameter
x = dbh

Parameter estimates of this pdf are determined using the parameter recovery procedure introduced by Hyink (1980). A theoretical discussion of this procedure to diameter distribution modelling is given by Frazier (1981), Matney and Sullivan (1982), Cao et al. (1982), and Hyink and Moser (1983). The parameter recovery system is based on the method of moments technique of pdf parameter estimation as discussed by Mendenhall and Scheafer (1983). For a diameter distribution, the first and second moments about the origin are given by

(2) $$E(x) = x_i/N = \bar{x} = D$$

(3) $$E(x^2) = x_i^2/N = B/0.00007854N = \overline{x^2}$$

where

$\bar{x}$ = the arithmetic mean diameter of the stand (D)
$\overline{x^2}$ = the quadratic mean diameter of the stand
N = stems per hectare
B = basal area per hectare

Stand average estimates of D, B, and N, for the first and second noncentral moments of the Weibull pdf, were determined with the following equations:

(4) $$D = \exp[-0.455+0.254\ \ln(H)+0.7631\ \ln(A)+0.03195\ \ln(B)]$$

$R^2 = 0.45$ MSE = 0.35

(5) $$B = \exp[-3.347+0.003069(A)+0.99259\ \ln(SDI)+0.13046\ \ln(H)-4.31(1/A)]$$

$R^2 = 0.97$ MSE = 3.25

$$(6)\quad N = \exp[7.3599-0.02471(A)+0.8228 \ln(B)-1.022 \ln(H)+0.18025(B/A)]$$

$R^2 = 0.88$ MSE = 25.8

Estimates of B at several projection ages were determined with the following equation:

$$(7)\quad B = \exp\{(A_i/A_{i+1})\ln(B_i)+(A_i/A_{i+1}) +0.04919[1-(A_i/A_{i+1})]S\}$$

$R^2 = 0.97$ MSE = 4.75

where

A_i = current stand age
A_{i+1} = projected stand age
B_i = current basal area
B_{i+1} = projected basal area
S = site index

The system of equations to solve for the parameter estimates of the Weibull pdf is

$$(8)\quad \bar{x} = \int_0^{\alpha} x f(x;b,c)dx = a+b\Gamma(1+1/c)$$

and

$$(9)\quad \overline{x^2} = \int_0^{\alpha} x^2 f(x;b,c)dx = a+b^2\Gamma(1+2/c)$$

The estimated variance (s^2) and coefficient of variation (CV) of the distribution are given by

$$(10)\quad s^2 = [\overline{x^2} - \bar{x}^2] = b^2 [\Gamma(1+2/c) - \Gamma^2(1+1/c)]$$

$$(11)\quad CV = (s/x) = \frac{[\Gamma(1+2/c) - \Gamma^2(1+1/c)]^{1/2}}{\Gamma(1+1/c)}$$

where

Γ = the gamma function.

The location parameter (a) of the Weibull pdf is predicted outside the system of equations to avoid convergence problems during the process of parameter estimation (Cao and Burkhart 1984, Knoebel et al. 1986). Parameter (a) is considered to be the smallest possible diameter in the stand (Bailey and Dell 1973, Rennolls et al. 1985). Given stand average estimates of x and x^2, there exists a unique solution for c in equation (11), and the value of this parameter can be obtained using iterative techniques. Equation (8) can be solved for b given that c is known, and the value for the location parameter (a) is a constant estimated as follows

$$(12)\quad a = \min(DBH) = \max[0.5932 - 0.16567(B)+0.95998(Dq)]$$

$R^2 = 0.89$ MSE = 0.85

Given initial conditions of stand age, dominant height, and basal area, the prediction of min(DBH), D, and Dq is necessary for solving the moment-based three parameter system of equations. A computer solution routine developed by Burk and Burkhart (1984) was used to solve for the Weibull parameter estimates. The program is based on a set of iterative routines which uses a combination of the bisection and secant methods for finding roots of nonlinear equations (Devroye 1986). These routines are used to provide a solution of $f(x;\theta)$ in order to recover the diameter distribution of the stand.

Total per unit area values of the stand attribute Y can be obtained for a given solution of $f(x;\theta)$. That is

$$(13)\quad Y = [N \int_{x_1}^{x_2} f(x;\theta)dx]g_i(x)$$

where

$f(x;\theta)$ = the Weibull pdf for x
$g_i(x)$ = stand attribute as a function of x
x_1 and x_2 = lower and upper diameter limits for the product described by $g_i(x)$

The probability that x lies in the diameter class (x_1, x_2) is found by integrating the probability density function $f(x;\theta)$ between the limits x_1 and x_2. That is

$$(14)\quad Prob(x_1 < x_2) = f(x;\theta)dx = \{\exp[-x_2-a/b)^c]\} - \exp[-x_1-a/b)^c$$

Tree-Level Equations

Diameter distribution growth and yield models require an estimate of mean tree height in each diameter class in order to determine the mean tree volume of each class. Several techniques have been proposed (Lenhart and Clutter 1971, Matney and Sullivan 1982). In this study, the mean tree height (HM) in each diameter class (DC) of each plot was first determined. The resulting HM observations of 1750 plots were then fit to develop the following equation:

$$(15)\quad HM = \exp[-0.1985+0.2258 \ln(D)-0.00987 \ln(B) - 1.3791(1/A)+0.8152 \ln(H)]$$

$R^2 = 0.93$ MSE = 2.25

A similar technique developed by Burk and Burkhart (1984) was used to predict the probability (P) that a tree is of sawtimber quality. The product class information of each tree for all the plots

of this study was assessed using a nonlinear taper equation for this species. To qualify as sawtimber, trees met the following criteria: length of first log larger than 6m, and a top diameter of that log larger than 25cm. The model to estimate P was as follows:

$$(16)\ P = \{1.0/[1.0+\exp(11.6598-0.030327(DBH) - 0.14317(TH))]\}$$

$$R^2 = 0.85 \qquad MSE = 0.013$$

Equations for predicting site index, stem taper, stem volume, and commercial volume to a diameter limit were developed as a part of this study.

COMPUTER PROGRAM

The computer program consists of stand average and tree-level equations and of a computer solution routine to solve for the Weibull parameter estimates. Given initial stand conditions for stand age, dominant height, and basal area, the program computes the stand site index, stem per hectare, stand density index, quadratic mean diameter, arithmetic mean diameter, and the Weibull parameter estimates. For the same initial conditions, the program also produces the corresponding stand-stock table. Once the stand-stock table is displayed, the user has the option of projecting the stand conditions into the future or terminating the program (figure 1). Source code for the computer program is available from the authors.

Given a solution for $f(x;\Theta)$, the proportion of the total number of trees (p_i) in a diameter class (w_i) was determined as follows:

$$p_i = \int_{x_1}^{x_2} f(x;\Theta)$$

and the number of trees (n) in the diameter class w_i was computed as $n = p_i * N$. Equations to predict tree height, tree basal area, total and commercial tree volume, and the probability of sawtimber were then used to calculate the g(x) stand attributes in the stand-stock table. Midpoint DBH's were used to compute class basal area, mean tree height, and volumes. This procedure may result in some small bias in the estimation of basal area and volume in each diameter class. The magnitude of this bias, however, is not significant for practical purposes. Numerical integration techniques can be used to reduce the bias which results from using midpoint diameter classes (Hafley et al. 1982).

A sensitivity analysis of the parameter recovery model was conducted to analyze its behavior with respect to changes in stand age, site index, and stand density. For a random sample of 250 plots from the 1850 temporary plots, the algorithm to solve for the Weibull parameter estimates converged on all plots used for this analysis. Stand average equations used to compute the first and second moments of the Weibull distribution performed quite well for estimating the parameter estimates. Diameter distributions estimated for a wide range of stand conditions showed that the frequency of trees in each diameter class decreases as the stand age increases (figure 2). The number of diameter

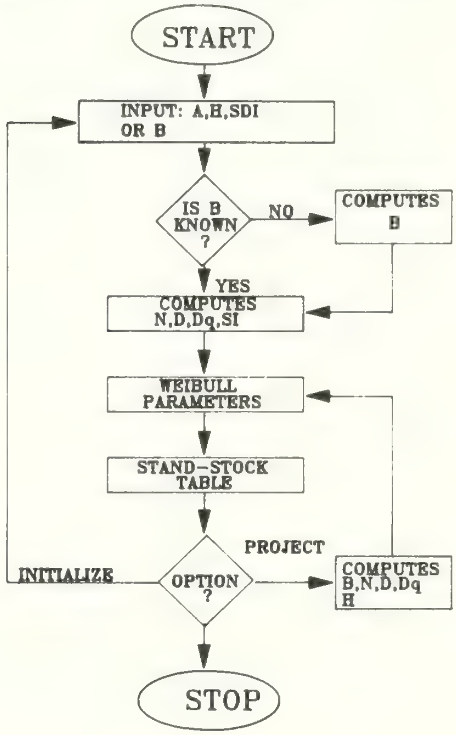

Figure 1.— Flow diagram to compute stand-stock tables using the Weibull parameter recovery model.

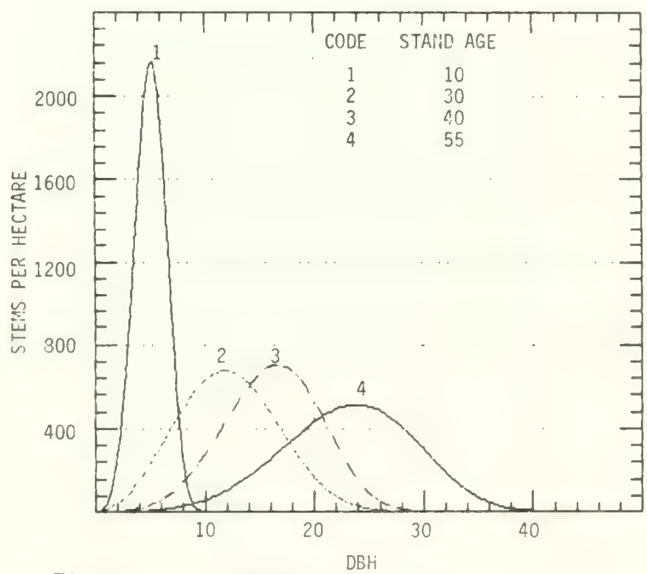

Figure 2.— Diameter distributions at several projection ages estimated with the Weibull parameter recovery model.

classes and trees in each diameter class, as well as the degree of skewness of the diameter distribution increases at higher site indices and stand basal areas. Merchantable volume increases with age and site index, and decreases if the stand is developing at higher stand densities. Stand-stock tables generated with this model are presented in Appendix 1.

MODEL VALIDATION

The performance of the model for recovering the parameter estimates of the diameter distribution were evaluated using an independent sample of validation data. Three statistical tests were used: Kolmogorov-Smirnov goodness of fit, Chi-square goodness of fit, and the sign test. The Kolmogorov-Smirnov statistic (K-S) compares the observed and the recovered distributions (Massey 1951). That is,

$$k = \max \left| F_0(x) - S_n(x) \right|$$

where

$F_0(x)$ = hypothesized $f(x;\theta)$ obtained with the parameter recovery procedure

$S_n(x)$ = the observed distribution of the n trees on the plot.

Both distributions are significantly different if the computed value of k exceeds the critical value $k_\alpha(n)$. The Chi-square statistic is determined as follows:

$$X^2 = \Sigma \left[\frac{E_i - O_i}{E_i} \right]$$

where

E_i = the expected frequency of trees in the diameter class w_i

O_i = the observed frequency of trees in the diameter class w_i

z = the number of diameter classes w_i $(i=1,\ldots,z)$

Larger values of the computed X^2 statistic indicate that the recovered distribution is different than the observed distribution. The sign test is a nonparametric test for differences between paired observations of a sample. For this test, maximum likelihood Weibull parameter estimates for the validation plots were determined using the procedure developed by Zutter et al. (1982). These parameter estimates were then compared with the parameter estimates obtained with the parameter recovery procedure. The statistic of this test is N(0,1) and is used to compare if the parameter estimates of both samples belong to the same population mean.

The goodness of fit tests indicated that most of the recovered diameter distributions were comparable to the diameter distributions of the validation data. Comparisons of K-S statistics

Table 1.-- Results of the goodness of fit tests of comparing the recovered diameter distributions with the observed diameter distributions of the validation data.

Range of Age	Number of Plots	Trees per Plot	No.(%) Plots Rejected	
			X^2	K-S
10-25	15	135	4(26.6)	3(20.0)
25-40	25	80	5(20.0)	4(16.0)
40-55	20	55	2(10.0)	3(15.0)
> 55	10	43	3(30.0)	2(20.0)

with the critical values ($k_\alpha(n)$) were not statistically significant in more than 75% of the plots for validation (α = 0.01). Values for the K-S statistics tended to increase at younger (10 to 25 years) and older ages (> 55 years). Similar results were obtained using the Chi-square goodness of fit statistics (table 1). Both tests indicated that the diameter distributions were poorly recovered at stand ages greater than 55 years. Test statistics above this age might be biased due to the few diameter classes in each plot and the low frequency of trees in each diameter class.

Parameter estimates obtained with the parameter recovery model compared quite well with the maximum likelihood parameter estimates. Sign tests were statistically significant (α = 0.001) for more than 90% of the validation plots. The recovered parameter estimates were positively biased. However, the amount of bias was insignificant for practical purposes. The location parameter exhibited more bias than the scale and range parameters. Bias in the location parameter is attributed to its procedure of estimation. Estimates of min(DBH) are always greater than or equal to the true smallest diameter in the stand. The small bias of the scale and shape parameters might be related to the bias of the scale and shape parameter (Frazier 1981). In general, the validation results suggest that the recovered diameter distributions were no different from the observed distributions of the validation plots.

CONCLUSION

The parameter recovery technique used in this study provides a reliable description of the diameter distribution of natural even-aged stand of Pinus cooperii. Predictions and projections of the stand diameter structure were highly dependent upon the performance of equations to predict and project average stand attributes. Goodness of fit tests indicated that the model produced diameter distributions similar to observed distributions in the validation data. For the same data, the Weibull parameter estimates obtained with this model were statistically similar to the maximum likelihood estimates. Stand-tables generated with

this model provide detailed information about the stand structure for a wide range of ages, site qualities, and stand densities. It is suggested that the use of remeasured data from larger plots might significantly improve the efficiency of this technique for recovering diameter distributions.

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APPENDIX 1

INITIAL CONDITIONS:

AGE: 40 Years
SITE INDEX (Base 60): 25m
BASAL AREA: 32m²
TREES PER HECTARE: 560
DOM./CODOM. HEIGHT : 19m
ARITHMETIC MEAN DBH: 26.4cm
QUADRATIC MEAN DBH: 27.2cm
STAND DENSITY INDEX: 491
WEIBULL PARAMETER EST.s:
Location: 20.113
Scale: 6.335
Shape: 1.004

STAND/STOCK TABLE

DBH (cm)	TREES /HA.	Ba.AREA m²/HA.	TOT. HEIGHT (m)	MERCH. VOL.(m^3) 10cm OB top	TOTAL STEM VOL .0cm OB top
20	175.2	5.5	17	0	49
25	210.5	10.3	18	16	96
30	95.6	6.8	18	33	65
35	43.2	4.2	19	35	42
40	19.5	2.5	20	24	25
45	8.8	1.4	21	15	15
50	4.0	.8	21	8	8
55	1.8	.4	21	5	5
60	.8	.2	21	3	3
65	.4	.1	22	1	1
70	.2	.1	22	1	1
75	.1	.0	23	0	0
TOTAL	559.9	32.2	----	141	311

PROJECTED CONDITIONS:

AGE: 45 Years
SITE INDEX (Base 60): 25m
BASAL AREA: 36m²
TREES PER HECTARE: 529
DOM./CODOM. HEIGHT : 20m
ARITHMETIC MEAN DBH: 28.7cm
QUADRATIC MEAN DBH: 29.5cm
STAND DENSITY INDEX: 691
WEIBULL PARAMETER EST.s:
Location: 21.765
Scale: 6.968
Shape: 1.003

STAND/STOCK TABLE

DBH (cm)	TREES /HA.	Ba.AREA m²/HA.	TOT. HEIGHT (m)	MERCH. VOL.(m^3) 10cm OB top	TOTAL STEM VOL .0cm OB top
20	52.6	1.7	18	0	15
25	243.9	12.0	18	22	117
30	119.3	8.4	19	46	86
35	58.1	5.6	20	50	59
40	28.3	3.6	21	37	38
45	13.7	2.2	21	24	24
50	6.7	1.3	22	15	15
55	3.2	.8	22	9	9
60	1.6	.4	23	5	5
65	.8	.3	23	3	3
70	.4	.1	23	2	2
75	.2	.1	24	1	1
80	.1	.0	24	1	1
TOTAL	528.7	36.4	----	215	375

PROJECTED CONDITIONS:

AGE: 50 Years
SITE INDEX (Base 60): 25m
BASAL AREA: 40m²
TREES PER HECTARE: 461
DOM./CODOM. HEIGHT : 22m
ARITHMETIC MEAN DBH: 32.2cm
QUADRATIC MEAN DBH: 33.1cm
STAND DENSITY INDEX: 722
WEIBULL PARAMETER EST.s:
Location: 24.588
Scale: 7.599
Shape: 1.001

STAND/STOCK TABLE

DBH (cm)	TREES /HA.	Ba.AREA m²/HA.	TOT. HEIGHT (m)	MERCH. VOL.(m^3) 10cm OB top	TOTAL STEM VOL .0cm OB top
25	146.6	7.2	20	16	75
30	151.7	10.7	21	69	117
35	78.6	7.6	21	74	85
40	40.7	5.1	22	57	59
45	21.0	3.3	23	39	40
50	10.9	2.1	23	26	26
55	5.6	1.3	24	17	17
60	2.9	.8	24	10	10
65	1.5	.5	25	6	6
70	.8	.3	25	4	4
75	.4	.2	25	2	2
80	.2	.1	26	1	1
85	.1	.1	26	1	1
90	.1	.0	26	0	0
TOTAL	461.1	39.4	----	325	445

PROJECTED CONDITIONS:

AGE: 55 Years
SITE INDEX (Base 60): 25m
BASAL AREA: 43m²
TREES PER HECTARE: 403
DOM./CODOM. HEIGHT : 24m
ARITHMETIC MEAN DBH: 35.8cm
QUADRATIC MEAN DBH: 36.7cm
STAND DENSITY INDEX: 744
WEIBULL PARAMETER EST.s:
Location: 27.559
Scale: 8.207
Shape: 1.005

STAND/STOCK TABLE

DBH (cm)	TREES /HA.	Ba.AREA m²/HA.	TOT. HEIGHT (m)	MERCH. VOL.(m^3) 10cm OB top	TOTAL STEM VOL .0cm OB top
30	181.9	12.9	22	93	148
35	101.1	9.7	23	103	116
40	54.9	6.9	23	82	85
45	29.8	4.7	24	59	60
50	16.1	3.2	24	41	41
55	8.7	2.1	25	27	27
60	4.7	1.3	26	18	18
65	2.6	.8	26	12	12
70	1.4	.5	26	7	7
75	.7	.3	27	5	5
80	.4	.2	27	3	3
85	.2	.1	28	2	2
90	.1	.1	28	1	1
95	.1	.0	28	1	1
TOTAL	402.8	43.0	----	453	524

PROJECTED CONDITIONS:

AGE: 60 Years
SITE INDEX (Base 60): 25m
BASAL AREA: 45m²
TREES PER HECTARE: 353
DOM./CODOM. HEIGHT : 25m
ARITHMETIC MEAN DBH: 39.4cm
QUADRATIC MEAN DBH: 40.4cm
STAND DENSITY INDEX: 761
WEIBULL PARAMETER EST.s:
Location: 30.686
Scale: 8.767
Shape: 1.006

STAND/STOCK TABLE

DBH (cm)	TREES /HA.	Ba.AREA m²/HA.	TOT. HEIGHT (m)	MERCH. VOL.(m^3) 10cm OB top	TOTAL STEM VOL .0cm OB top
30	65.4	4.6	23	37	56
35	125.0	12.0	24	135	150
40	70.9	8.9	24	111	114
45	40.0	6.4	25	83	84
50	22.5	4.4	26	59	60
55	12.7	3.0	26	41	41
60	7.1	2.0	27	28	28
65	4.0	1.3	27	19	19
70	2.2	.9	28	13	13
75	1.3	.6	28	8	8
80	.7	.4	28	5	5
85	.4	.2	29	3	3
90	.2	.1	29	2	2
95	.1	.1	30	1	1
100	.1	.1	30	1	1
TOTAL	352.7	45.0	----	548	585

Factors Affecting Ponderosa Pine Forest Resource Outputs: Moderator's Comments

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The multiresource management of the public forests of the U.S. is mandated by federal legislation directing land management agencies to consider all resource outputs in their management decisions. Many factors including political constraints, paucity of site specific ecological data, and shortage of decision support methodology currently limit the implementation of multiresource management. This section of the conference proceedings focuses on some of the ecological factors that limit the accomplishment of multiresource goals and suggests some methodology for mitigating these factors.

Insects and diseases have been long recognized as important factors limiting the wood fiber production of forests. It is only recently that their effects on the other resource outputs such as recreation, aesthetics, water, grazing, and wildlife have been recognized. This historical precedence has led to a situation where methods are critically needed to assess the impacts of pests on these other mostly non-commodity outputs. While the long term solution will require considerable research effort, an interim qualitative technique, presented in this section, will permit the assessment of some of these factors. A second important reason why insects and disease effects have not been managed as effectively as possible relates to decision making processes. The successful management of pest species that affect multiresource outputs is dependent on integrating pest management into forest management through a process called integrated pest management (IPM). IPM has, to a large extent, not been practiced on public forest land. In this section a procedure for integrating pest management into forest management through the Integrated Resource Management (IRM) philosophy is presented. The IRM process in conjunction with an interdisciplinary approach is presented as the most expeditious method to accomplish IPM and reduce the negative effect of pests on multiresource outputs.

Competing vegetation and site nutrient status are also factors that influence multiresource outputs. Political constraints have largely precluded the use of herbicides as a broad scale approach to managing competing vegetation. The use of livestock to achieve reduction in competing vegetation is an alternative method with considerable potential. Research results presented indicated that with careful management, collateral production of timber and livestock is feasible. Likewise, the careful management of fire can be an effective tool in achieving multiresource objectives. These objectives can only be achieved however, if careful attention is paid to factors such as season and intensity of fire. Research results are presented in this section that have implications for the appropriate use of prescribed fire to reduce fuels and improve site nutrient status.

Finally, the section concludes with a discussion of ponderosa pine tissue culture. The ever increasing demands on forests will likely justify the application of tree improvement methods. Many managers tend to view tree improvement methods such as genetic engineering and tissue culture as inconsistent with multiresource objectives. In reality, the methods can be used to enhance visual quality, biodiversity, wildlife habitat, etc., equally as well as enhancing fiber production. It is only the application of tissue culture methods, not the methods themselves, that limit their utilization.

Forest land managers will certainly need to consider and be aware of these and other factors that will ultimately limit the outputs of multiresource management of the ponderosa pine forest.

Assessing the Impacts of Foliage-Feeding Insects on Timber and Scenic Beauty of Ponderosa Pine: A Methodological Approach[1]

Joel D. McMillin[2] and Michael R. Wagner[3]

Abstract.--In this paper we discuss impacts caused by insect defoliation on multiresource outputs (timber and scenic beauty) of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) forests. Hypothetical response functions for insect defoliation impacts on timber and scenic beauty resource outputs are proposed based on a review of the literature. For each functional relationship suggested, species dependent factors are determined and used to qualitatively assess the impact of foliage feeding. Selected insects are assigned quantitative ratings and ranked in high, moderate, and low impact categories. Implications of an insect's status as an economical or non-economical pest are discussed. The potential applications and limitations of this method to assess the impacts of insects on multiresource outputs are discussed.

INTRODUCTION

Today's forest may be thought of as a "multi-product factory"; with the forest manager trying to optimize all factory outputs. Commodities that are produced from an efficiently managed multi-resource forest include: timber products, range for livestock, recreation facilities including hunting and fishing, wildlife habitat, and water. Because forest planners feel pressure from special interest groups they need to manage forests economically while meeting the various and sometimes conflicting demands of the general public. Many factors influence the optimization of forest outputs; considering all of these factors is important to the efficiency of multiresource forestry.

One of these factors that has been widely studied is the impact of insects on forest outputs. The importance of forest insects range from beneficial impacts to extensive losses of timber production. Forest insects can adversely affect timber production, wood products, scenic beauty and recreational values by damaging the quality of timber, by causing delays in growth rates, or by thinning and discoloring of foliage. While tree killing by bark beetles and subsequent damage by wood boring insects may cause the most timber losses, certain defoliating insects also effect timber production and quality. Defoliators damage forests by consuming the foliage that produces photosynthate thereby reducing the growth rates of trees. But they can also kill vast stands of forest during population outbreaks.

Timber has historically been viewed as the major economic product of forests, consequently the focus of insect research has been on how insects affect timber production. Because of the wood products focus, there is relatively little literature on other impacts of insects (e.g. recreation, scenic beauty). In recent years there has been an increasing interest in non-timber resources values. Currently there is inadequate information on how specific insects may effect timber and non-timber resources simultaneously. For example, an insect species may have relatively little economical importance in terms of timber, but may cause significant

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declines in recreation usage, or decreases in aesthetic value. Understanding how insects influence several multiresource outputs concurrently may aid the forest manager in optimizing all of the resource outputs. Thus, the need to systematically assess all resource impacts of insects and to develop some general hypotheses of how they effect non-timber resources is critical in managing today's forests.

In this paper we evaluate one section of the above mentioned need to analyze the impacts of insects on multiresource outputs. We concentrate on defoliating insects and their relative impacts on timber and scenic beauty of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) as a model for how multiresource impacts of insects can be assessed. We review pertinent literature in order to develop generalized response functions between insect-damaged foliage and impacts on timber and scenic beauty. Based on these functional relationships, factors determined to be species specific, or species dependent, are utilized to qualitatively assess the impact of foliage feeding insects. And in turn these insects are assigned quantitative ratings and ranked in impact intensity categorries. The implications of an insect's status as an economical or non-economical pest in a broader multiresource category are then evaluated.

Impacts of Insects on Timber

Forest planners need to understand the impacts on tree growth rates by feeding insects if they are to accurately estimate multiresource outputs and/or decide to implement pest control practices. Damage to tree foliage causes disruptions in a variety of growth processes. For example, defoliation that results in a reduction of photosynthesis and a decrease in the production of carbohydrates may lead to a decline in growth hormones and other plant materials needed for cambial growth (Kozlowski 1971, Barbosa and Wagner 1989). Insect defoliators cause a wide variety of changes in the forest ranging from insignificant alterations, such as temporarily reduced growth in individual trees, to more economically important changes and impacts like severe growth loss, species composition changes in the forest stand, and complete stand mortality (Kozlowski 1971, Kulman 1971). There are several interrelated factors which influence the severity of impact on tree growth caused by defoliators. Factors known to influence the impact of defoliation include: preponderance for species outbreak (frequency and length of outbreak), degree or intensity of defoliation (amount of foliage removed), timing of defoliation (early season versus late season), and the age class of needle being damaged.

While growth reductions due to endemic populations are usually low or imperceptible, critical reductions or delays in growth occur during and following epidemics (outbreaks) (Mattson and Addy 1975, Furniss and Carolin 1977). Insects vary in their frequency of population outbreaks. Some species may never reach epidemic levels, others only after long intervals of time, while a few frequently rise to large population numbers. During periods of sustained population outbreak, defoliators are able to destroy timber over large areas (Furniss and Carolin 1977). For example, *Neophasia menapia* (Felder and Felder) has had devastating impacts on timber production during outbreaks (Cole 1966), but these outbreaks have been infrequent. In contrast *Orgyia pseudotsugata* (McDunnough) has destroyed enormous areas of forest stands during outbreaks and these outbreaks occur frequently (Furniss and Carolin 1977).

Light defoliation for one or more years may cause little or no reduction in annual growth while heavy defoliation can result in severe growth reduction for several years or even mortality (Kulman 1971, Mattson and Addy 1975). In general, studies have shown that timber losses are proportional to the amount of foliage removed (Kulman 1971), however the losses are also closely related to the timing of defoliation and the age class of needles being damaged (Kozlowski 1971). Early season feeding is considered to be feeding that occurs on previous years' growth prior to needle expansion (prefoliage flush). Early defoliation of ponderosa pine does not affect the flush of that season's foliage and damage is often confined to minimal reductions of growth rates. Defoliation of ponderosa pine current year needles later in the summer (post-foliage flush), occurs after the tree is capable of producing another needle flush. Therefore defoliation before foliage flush permits the pines to refoliate, form buds for the next year, and recover before winter (Kozlowski 1971, Britton 1988). Thus insect feeding on ponderosa pine late in the growing season, at either low or high defoliation intensities, has a much more negative impact on timber production than early in the growing season (Figure 1).

Similarly, defoliation of old growth, or previous years' needles, (independent of the timing of defoliation) has relatively little effect on tree growth in comparison to defoliation of current-year foliage which generally causes more extreme growth reductions (Kulman 1965, Kozlowski 1971)(Figure 2). These differences in growth reductions are due to the higher photosynthetic efficiency of current-year needles (Kulman 1965).

Impacts of Insects on Scenic Beauty

The National Environment Policy Act of 1969 and the Multiple Use Sustained Yield Act of 1960 mandated forest managers to assess non-timber products in addition to timber products (Buhyoff and Leuschner 1978). Insect damage plays an important role in a forest manager's optimiza-

tion of these non-timber products of a multi-resource forest. Leuschner and Young (1978) found that southern pine beetle (*Dendroctonus frontalis* Zimm) caused greater economical damage to recreation sites than to timber. Thus, it is evident that the forest manager must consider to what degree insect-caused damage influences non-timber products, in order to truly assess all economic concerns. The non-timber product assessed in this paper is scenic beauty. Species specific factors which we believe influence the severity of defoliation impact on scenic beauty include: the nature of defoliation, distribution of feeding damage, and preponderance for species outbreak.

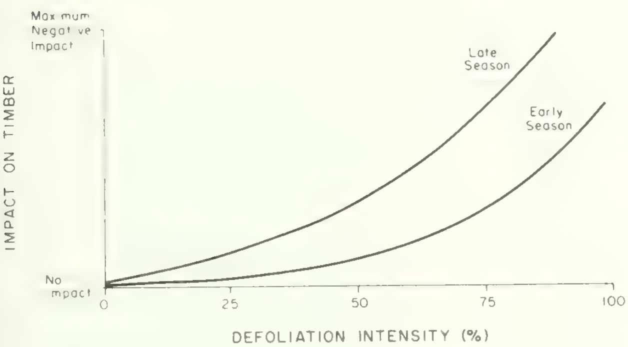

Figure 1.--Hypothetical response functions comparing early season (before natural foliage flush) and late season (post foliage flush) defoliation of current ponderosa pine foliage as they influence the relationship of defoliation intensity to resource impact.

A variety of feeding strategies are utilized by insects to attack pine needles. Feeding practices involve chewing, sucking, needle mining, and gall forming (Furniss and Carolin

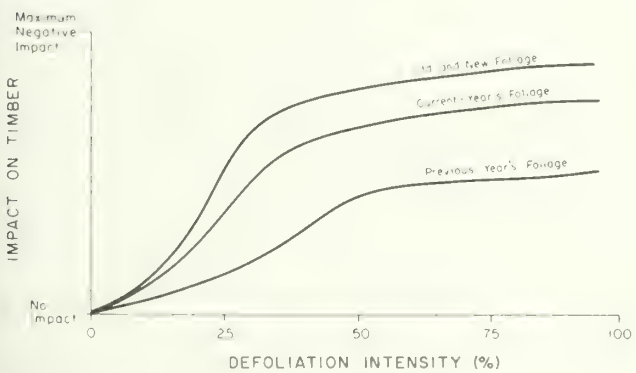

Figure 2.--Hypothetical response functions for timber impacts based on ponderosa pine defoliation intensity and foliage age class removed.

1977). The nature of feeding often determines if the foliage becomes discolored, dies prematurely, or is completely removed, and, in turn, influences the impact on scenic beauty. Discoloration of foliage due to insect feeding is noticed at low levels by the public (Buhyoff et al. 1982) and generally has a negative impact on scenic beauty (Buhyoff and Leuschner 1978) (Figure 3). Insects that do not cause visible color change, but which completely defoliate needles, may be less apparent (Krisko 1988).

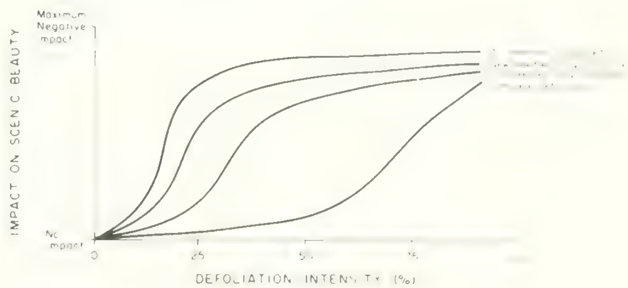

Figure 3.--Hypothetical response functions for the impact of defoliation intensity and foliage damage category on scenic beauty.

For example, defoliation by pandora moth (*Coloradia pandora* Blake) in Grand Canyon National Park was perceived by the public, but only at high levels (Krisko 1988).

The general public's perception of scenic quality may be influenced in part by the location in which they detect insect damage (Anderson 1981, Ribe 1989) (Figure 4). For example, low levels of defoliation and discoloration thinly scattered over a broad area may be "masked" or may even have a positive impact on scenic beauty when viewed from a roadside overlooking an expansive vista (Buhyoff and Leuschner 1978). The same level of defoliation

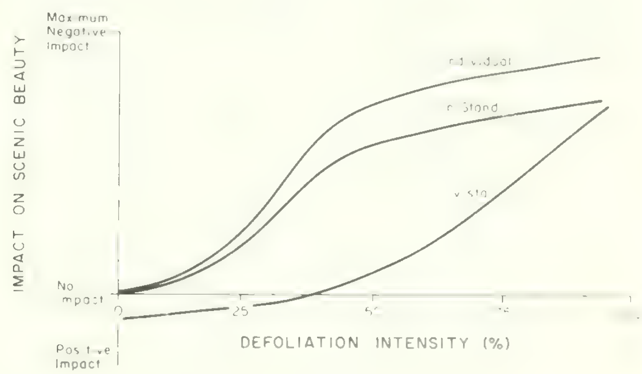

Figure 4.--Hypothetical response functions comparing perspective of view (individual tree, stand, and vista) as a relationship of defoliation intensity and scenic beauty.

and discoloration may have a negative impact on scenic beauty, however, when observed by a hiker trekking through a open forest stand.

As in insect impacts on timber, frequency and intensity of outbreak influences the degree of impact on scenic beauty. For example, although *Coleotechnites* spp have only moderate impacts on timber production due to its feeding on predominantly older needles (Stevens 1973, Stevens and Leatherman 1982), this species would have a relatively high negative impact on scenic beauty owing to its sustained population outbreak causing discoloration over large areas.

Important Defoliators of Ponderosa Pine

Furniss and Carolin (1977) list six orders and twenty-two families of insects known to damage ponderosa pine foliage. The orders with the most ponderosa pine defoliators are Lepidoptera, Hymenoptera, and Coleoptera; with the Lepidoptera order containing the most species generally considered to be destructive. Those species which exhibit low or no impacts on timber and scenic beauty were not included in our qualitatative assessment, but they may be important species in influencing other multiresource outputs such as wildlife and recreation. Therefore, seventeen species out of fifty-four total species of defoliators or foliage-damaging insects were assessed (Table 1).

Table 1.--Ponderosa pine foliage feeding insects and the nature of their feeding damage.

Order/Family	Scientific Name	Common Name[1]	Nature of Feeding
Coleoptera:Chrysomelidae	*Glyptoscelis illustris*	leaf beetle	Adults feed on foliage during spring and summer.
Coleoptera:Scarabaeidae	*Phyllophaga falsa*	scarab beetle	Adults feed on foliage and may cause damage to seedlings in plantations.
Coleoptera:Curclionidae	*Cylindrocopturus eatoni*	pine reproduction weevil	Adults feed from June to August and may damage trees in plantations. Causes discoloration of foliage.
Coleoptera:Curclionidae	*Scythropus californicus*	elegant pine weevil	Adults feed on old foliage of of young trees during spring and summer.
Lepidoptera:Tortriciidae	*Choristoneura lambertiana*	sugar pine tortrix	Larvae mine needle sheaths when new shoots development is nearly complete.
Lepidoptera:Pieridae	*Neophasia menapia*	pine butterfly	Larvae generally attack older trees throughout the summer consuming new and old foliage.
Lepidoptera:Saturniidae	*Coloradia pandora*	pandora moth	Larvae present beginning in August. Defoliation noticeable in May of the following year.
Lepidoptera:Arctiidae	*Halisidota ingens*	webworm	Larvae construct webs on young trees and feed on upper foliage.
Lepidoptera:Lymantriidae	*Orgyia pseudotsugata*	douglas-fir tussock moth	Larvae feed on unfolding new needles causing them to die which gives the tree a strong reddish cast. As larvae mature, they feed on both new and old foliage through the summer.

Table 1.--Ponderosa pine foliage feeding insects and the nature of their feeding damage. (Continued)

Order/Family	Scientific Name	Common Name[1]	Nature of Feeding
Lepidoptera:Lymantriidae	*Parorgyia grisefacta*	pine tussock moth	Larvae feed on young pine during late summer and the following spring.
Lepidoptera:Noctuidae	*Euxoa excellens*	cutworm	Larvae feed on young seedlings in spring, damaging cotyledons and stems. Can be economical pests of nurseries.
Lepidoptera:Yponomeutidae	*Zelleria haimbachi*	pine needle sheathminer	Larvae feed on new growth throughout summer and the following spring. Feed at bases of needle clusters causing them to drop, die, and shed prematurely.
Lepidoptera:Gelechiidae	*Coleotechnites* spp.	needle miners	Sustained and destructive outbreaks can result in heavy discoloration and kill trees extensively.
Homoptera:Aphididae	*Pineus Coloradensis*	pine adelgid	The foliage of heavily attacked trees becomes yellowish and growth is retarded; white, waxy secretions are conspicuous on seedlings.
Homoptera:Diaspididae	*Nuculaspis californica*	black pine leaf scale	Sustained, heavy infestations for several years can weaken and kill trees of all sizes. Significantly affected trees have sparse, short foliage at the tips of branches.
Homoptera:Margaroididae	*Matsucoccus* spp.	pine scale	Epidemic populations in Arizona and New Mexico have caused extensive twig blight.
Hymenoptera:Diprionidae	*Neodiprion* spp.	pine sawflies	Larvae generally feed on pole-sized trees, but attack trees of all ages depending on the species. Feeding can weaken affected trees and reduce growth; mortality may also occur. Under some conditions sawflies can cause defoliation over an extensive area.

[1]Common names based on Sutherland (1978) or Furniss and Carolin (1977).

Methods to quantitatively assess potential impacts

Because of paucity of data, qualitative judgments were used to initially assess the foliage feeding insects. The insects selected were assigned relative values according to their feeding habits and life histories. Based on our knowledge of defoliation patterns of individual species and the hypothetical response functions developed from the literature, we categorized defoliators into impact intensity groups.

The insects were assessed for factors which influence timber production and scenic beauty (Table 2). For timber production these factors included: (1) preponderance for species outbreak, (2) age class of foliage fed upon, and (3) season of feeding. And factors evaluated which affect scenic beauty included: (1) prepon-

Table 2.--Criteria used to qualitatively assess the affects of foliage feeding insects on timber production and scenic beauty.

I. Timber
- A. Preponderance for Outbreak
  - 0 - no evidence of outbreak
  - 1 - rarely reaches epidemic levels
  - 2 - evidence of outbreak, but infrequent and not destructive
  - 3 - frequent outbreaks, but not destructive or sustained
  - 4 - infrequent outbreaks, destructive and sustained
  - 5 - frequent, sustained periods of destructive outbreak
- B. Age Class of Foliage Being Fed Upon
  - 0 - partial old growth
  - 1 - complete old growth
  - 2 - partial new growth
  - 3 - partial new growth and old growth
  - 4 - complete new growth
  - 5 - complete new growth and old growth
- C. Seasonal Timing of Feeding
  - 0 - partial, pre-needle expansion
  - 1 - complete, pre-needle expansion
  - 2 - partial, early summer, post-needle expansion
  - 3 - partial, late summer, post-needle expansion
  - 4 - complete, early summer, post-needle expansion
  - 5 - complete, late summer, post-needle expansion

II. Scenic Beauty
- A. Preponderance for Outbreak
  - 0 - no evidence of outbreak
  - 1 - rarely reaches epidemic levels
  - 2 - evidence of outbreak, but infrequent and not destructive
  - 3 - frequent outbreaks, but not destructive or sustained
  - 4 - infrequent outbreaks, destructive and sustained
  - 5 - frequent, sustained periods of destructive outbreak
- B. Distribution of Feeding Damage
  - 0 - sparsely scattered over small area
  - 1 - sparsely scattered over large area
  - 2 - moderate over small area
  - 3 - moderate over large area
  - 4 - heavy over small area
  - 5 - heavy over large area
- C. Discoloration Due to Feeding Damage
  - 0 - no discoloration
  - 1 - light discoloration, or unsightly feeding habits
  - 2 - moderate discoloration, short period
  - 3 - moderate discoloration, extended period
  - 4 - heavy discoloration, short period
  - 5 - heavy discoloration, extended period

Table 3.--Selected foliage feeding insects of ponderosa pine qualitatively assessed for timber production and scenic beauty.[1]

Species	Timber	Scenic Beauty
Glyptoscelis illustris	A. 1 B. 2 C. 2 5	A. 1 B. 3 C. 0 4
Phyllophaga falsa	A. 2 B. 2 C. 2 6	A. 2 B. 4 C. 2 8
Cylindrocopturus eatoni	A. 2 B. 2 C. 2 6	A. 2 B. 3 C. 3 8
Scythropus californicus	A. 2 B. 0 C. 2 4	A. 2 B. 0 C. 2 4
Choristoneura lambertiana	A. 4 B. 4 C. 3 11	A. 4 B. 3 C. 4 11
Neophasia menapia	A. 4 B. 5 C. 4 13	A. 4 B. 5 C. 1 10

Table 3.--Selected foliage feeding insects of ponderosa pine qualitatively assessed for timber production and scenic beauty[1] (Continued)

Species		Timber	Scenic Beauty
Coloradia pandora	A.	4	4
	B.	1	5
	C.	1	0
		6	9
Halisidota ingens	A.	1	1
	B.	2	3
	C.	2	2
		5	6
Orgyia pseudotsugata	A.	4	4
	B.	5	5
	C.	4	4
		13	13
Parorgyia grisefacta	A.	2	2
	B.	3	3
	C.	3	3
		8	8
Euxoa excellens	A.	1	1
	B.	2	0
	C.	2	0
		5	1
Zelleria haimbachi	A.	3	3
	B.	2	2
	C.	1	5
		6	10
Coleotechnites spp.	A.	5	5
	B.	1	5
	C.	2	5
		8	15
Neodiprion spp.	A.	3	3
	B.	3	2
	C.	2	0
		8	5
Pineus coloradensis	A.	2	2
	B.	2	2
	C.	2	3
		6	7
Nuculaspis californica	A.	3	3
	B.	4	3
	C.	3	3
		10	9
Matsucoccus spp.	A.	2	2
	B.	3	4
	C.	3	5
		8	11

[1]The assessment values assigned to species pertain to the criteria listed in Table 2.

derance for species outbreak, (2) distribution of feeding damage, and (3) discoloration patterns due to feeding damage. The assigned values were then totaled and used to place the defoliators into impact intensity categories.

Results of quantitative assessment

To determine in which of the three impact intensity categories (high, moderate, or low) a species was placed, the qualitative assessment values derived in Table 3 were summed for timber and scenic beauty (Table 4). While the majority of species were placed in the same intensity category for both timber production and scenic beauty, there were some notable exceptions.

Orgyia pseudotsugata and *Choristoneura lambertiana* (Busck) have been frequently documented as being important economical pests of timber production (Furniss and Carolin 1977). Because of their recurrent population outbreaks which cause widespread defoliation of new needles and, in the case of *O. pseudotsugata*, strong discoloring of needles, these species can be considered to impact scenic beauty. While *Neophasia menapia* appears in the high impact intensity category for timber production, its impact on scenic beauty is relatively lower due to the nature of its feeding (complete defoliation compared with discoloration). For *Coleotechnites* spp. and *Matsucoccus* spp. the reverse is true. That is, these species have a high impact on scenic beauty, but only moderate impacts on timber production, owing to their feeding damage which causes extensive discoloration.

Insects placed in the moderate impact intensity category, although usually not regarded as economical pests of timber products, may cause significant damage to timber products and scenic beauty. The level of damage depends on whether populations reach epidemic proportions and on the timing of feeding or the nature of feeding damage. *Zelleria haimbachi* (Busck) has moderate impacts on timber production because of its normally low defoliation intensity early in the summer, but the resulting discoloration of needles it causes may lead to a strong negative impact on scenic beauty. Similarly, *Coloradia pandora* may have potentially

Table 4.--Ranking of selected species according to their relative impact on timber production and scenic beauty. The numbers in parentheses pertain to the total qualitative impact rating determined in table 4.

Impact Intensity	Timber Production		Scenic Beauty	
High (11-15)	*Orgyia pseudotsugata*	(13)	*Coleotechnites* spp.	(15)
	Neophasia menapia	(13)	*Orgyia pseudotsugata*	(13)
	Choristoneura lambertiana	(11)	*Choristoneura lambertiana*	(11)
			Matsucoccus spp.	(11)
Moderate (6-10)	*Nuculaspis californica*	(10)	*Neophasia menapia*	(10)
	Parorgyia grisefacta	(8)	*Zelleria haimbachi*	(10)
	Coleotechnites spp.	(8)	*Coloradia pandora*	(9)
	Neodiprion spp.	(8)	*Nuculaspis californica*	(9)
	Matsucoccus spp.	(8)	*Phyllophaga falsa*	(8)
	Phyllophaga falsa	(6)	*Cylindrocopturus eatoni*	(8)
	Cylindrocopturus eatoni	(6)	*Parorgyia grisefacta*	(8)
	Coloradia pandora	(6)	*Pineus coloradensis*	(7)
	Zelleria haimbachi	(6)	*Halisidota ingens*	(6)
	Pineus coloradensis	(6)		
Low (0-5)	*Glyptoscelis illustris*	(5)	*Neodiprion* spp.	(5)
	Halisidota ingens	(5)	*Glyptoscelis illustris*	(4)
	Euxoa excellens	(5)	*Scythropus californicus*	(4)
	Scythropus californicus	(4)	*Euxoa excellens*	(1)

high negative affects on scenic beauty because of its heavy feeding damage over a large area (albeit with no discoloration), but a relatively low impact on timber production due to its feeding on primarily previous year needles. In contrast, *Neodiprion* spp. may have a moderately high impact on timber production under certain conditions, while not inducing major impacts on scenic beauty because their feeding damage results in little discoloration usually over a small area.

Foliage feeding insects that ranked in the low impact intensity category may have relatively minor affects on timber production and scenic beauty due to the rarity of species outbreak, age class of foliage being damaged, seasonal timing of feeding, and/or the nature of the species feeding damage. For example, *Euxoa excellens* (Grote') rarely reaches epidemic levels and partially defoliates early in the summer over small areas. Therefore, although it can be an important pest of tree nurseries (Furniss and Carolin 1977), the impacts on natural forests are minimal. Likewise *Scythropus californicus* (Horn), which feeds on old foliage of ponderosa pine in spring and early summer, causes feeding damage that is sparsely scattered over small areas.

Implications

We have proposed in this paper a procedure to estimate the impact of some insects based on the patterns of defoliation without formal experiments. The procedure begins with reviewing literature to discover general patterns of impacts on timber or non-timber products effected by foliage feeding insects. These patterns are then used to develop hypothetical relationships as a function of the agent causing the impact and the multiresource output. Based on the relationships, criteria are derived by which the specific agent is qualitatively assessed. The resulting estimations serve as a guide to assessing impacts. It is important to point out that the methodology of this procedure is limited to species specific effects, and is not appropriate for evaluating factors which are independent of species.

Experimental verification of these response functions is critical prior to their widespread application. The procedure outlined above serves as a method to qualitatively assess potentially important insects and insect affects on timber and scenic beauty for further study. It is clear from analysis that some insect species warrant considerably more research attention than they have received to date. For example, the qualitative evaluations in this paper lead us to recognize that some non-economical species from a timber perspective could be very important from a scenic beauty standpoint (e.g. *Coleotechnites* species). More research on life histories of individual defoliating species needs to be performed to better understand the full impact of the defoliator. The methods developed here may have utility for other non-timber products such as recreation or wildlife. Ideally, a defoliating species would be assessed for its impacts on all multiresource outputs; and the impacts simultaneously weighed. This would enable the forest manager to make the most highly qualified decision on whether to implement pest control practices or to consider the species as an economical pest.

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Incorporating Pest Management into Land Management Decisions[1]

Borys M. Tkacz[2]

Abstract.--Implementation of Forest Plans in the Southwestern Region of the USDA Forest Service is following the Integrated Resource Management (IRM) philosophy which recognizes the intricate inter-relationships between all the natural resources. Forest Pest Management specialists are involved in all phases of IRM, from the initial development of project concepts and identification of concerns and opportunities related to insects and diseases to the analysis of treatment alternatives and the eventual project implementation and monitoring of success.

INTRODUCTION

A large portion of the public perceives a decline in the health of our Nation's forests. These concerns were partially triggered by recent outbreaks of gypsy moth, southern pine beetle, western spruce budworm and mountain pine beetle, as well as, publicity about the effects of atmospheric pollution on forests. In response to concerns emphasized by Members of Congress, the USDA Forest Service recently completed a report titled: "Forest Health Through Silviculture and Integrated Pest Management: A Strategic Plan" (U.S. Department of Agriculture 1988a). The objective of this plan is to "enhance and maintain the health of the Nation's forests ... through Forest Service programs and authorities". Forest health is defined as "a condition where biotic and abiotic influences on the forest (i.e. insects, diseases, atmospheric deposition, silvicultural treatments, harvesting practices) do not threaten management objectives for a given forest unit now or in the future".

One of the issues identified in this report was that pest management considerations are not adequately incorporated in forest resource management planning processes. Most Forest Plans mention but do not provide for practicing pest management and priorities for forest management activities rarely consider forest pest impacts. Most Forest Plan analyses projecting productivity did not make necessary adjustments for potential losses to forest pests. Failure to consider forest pest impacts in Forest Plan implementation projects could exacerbate existing and potential pest problems. The report recommends that the USDA Forest Service "require pest specialist input to National Forest System inter-disciplinary teams conducting forest resource management planning" (U.S. Department of Agriculture 1988a).

This presentation will outline how land managers and Forest Pest Management (FPM) specialists in the Southwestern Region are working toward incorporating pest management into land management decisions on a project-by-project basis.

PESTS OF PONDEROSA PINE

Management of ponderosa pine (Pinus ponderosa Laws. subsp. scopulorum Murray) in the Southwest is complicated by several pests. The most important disease is caused by southwestern dwarf mistletoe (Arceuthobium vaginatum (Wild.) Presl subsp. cryptopodum (Engelm.) Hawksw. & Wiens) (Beatty 1982). Recent surveys indicate that 39 percent of the commercial ponderosa pine acres on National Forests in Arizona and New Mexico are infected resulting in an annual loss in productivity of at least 20 million cubic feet per year (MMCF), or approximately 14 percent of estimated potential productivity (H. Maffei, personal communication, 1989). Root diseases caused by Armillaria sp. and

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Heterobasidion annosum (Fr.) Bref. annually kill an estimated 1.0 MMCF of ponderosa pine in Arizona and New Mexico (Wood 1983). Bark beetles, including engraver beetles (Ips spp.), western pine beetle (Dendroctonus brevicomis LeConte), and mountain pine beetle (Dendroctonus ponderosae Hopkins), are periodically destructive to ponderosa pines in the Southwest. Estimated volume losses caused by these insects in 1988 approximated 0.9 MMCF in Arizona and New Mexico (Rogers and Maffei 1989).

INTEGRATED RESOURCE MANAGEMENT

Forest health is a desired future condition. Although most Forest Plans gave us specific management objectives by area, they did not present a very clear picture of the desired forest conditions to meet them. Clear descriptions of desired future conditions for specific sites are needed for implementation of Forest Plans.

Implementation of Forest Plans in the Southwestern Region is following the Integrated Resource Management (IRM) philosophy which recognizes the intricate interrelationships between all the natural resources (U.S. Department of Agriculture 1988b). An inter-disciplinary (ID) approach is being utilized to design impact generating projects. Attempts are made to identify the resources involved, define the resource interrelationships and to reasonably predict the effects or impacts of projects. Project design and implementation follows a 13-phase process that closely parallels the NEPA (National Environmental Policy Act of 1969) process (fig. 1.). Forest Pest Management specialists in the Southwestern Region are involved throughout all phases of IRM.

To illustrate how pest management is incorporated into land management I will present the development of a timber sale on the Payson Ranger District of the Tonto National Forest. The Meads Timber Sale is located about 12 miles northeast of Payson, Arizona. The assessment area encompasses 5862 acres excluding 263 acres of private land. Timber stands within the analysis area consist of ponderosa pine and are generally 2 to 3 storied in structure. The most prevalent management age class is immature sawtimber (12-13 inches in diameter at breast height (DBH)) with small poles (6-9 inches DBH), large poles (9-12 inches DBH) and seedlings and saplings being about equally represented, but not equally distributed. There is a significant amount of woodland type (juniper/oak) within the analysis area. Past practices have included precommercial thinning pole stands and pulpwood and salvage harvesting with no attempts to provide for even-aged stands or to control dwarf mistletoe. Dwarf mistletoe infection of ponderosa pine is widespread within the analysis area.

SCOPING

1 REVIEW FOREST PLAN
2 DEVELOP PROJECT CONCEPT
3 CONDUCT EXTENSIVE RECON.
4 FEASIBILITY REPORT

ANALYSIS

5 IMPLEMENTATION SCHEDULE
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Figure 1.--Project implementation through Integrated Resource Management as it relates to the NEPA process.

SCOPING

The first phase in project planning is to determine how the proposed project may contribute to the accomplishment of Forest Plan goals and objectives and whether it conforms with standards and guidelines. Forest goals are desired conditions to be achieved sometime in the future. The Tonto National Forest Plan contains the following goal: "Through integrated pest management, manage resources to prevent a build-up of insects and diseases to prevent or reduce serious, long lasting hazards" (U.S. Department of Agriculture 1985). Forest objectives are measurable, planned outputs of resources that respond to pre-established goals. The timber yield projections on the Tonto National Forest included the effects of dwarf mistletoe as predicted by the RMYLD growth and yield simulator (Edminster 1978).

Forest-wide standards and guidelines provide general indications of policy. For example: "Important Forest insects and diseases will be monitored on an annual basis. Where conditions

indicate an impending build-up or outbreak is imminent, an evaluation will be conducted in order to formulate management alternatives to reduce loss to an acceptable level" (U.S. Department of Agriculture 1985).

More specific standards and guidelines are listed for each Management Area. These are mapped areas that have a common direction throughout that differs from neighboring areas. The Meads Timber Sale is within the 4D Management Area as identified by the Tonto National Forest Plan. Management emphasis is to manage for a variety of renewable resource outputs with primary emphasis on intensive, sustained yield timber management, timber resource protection, creation of wildlife habitat diversity, increased populations of emphasis harvest species, and recreation opportunity. Standards and guidelines for Management Area 4D include the following: "Integrate dwarf mistletoe surveys into stand examinations. Remove infected overstories as soon as regeneration is accomplished. Thin understories to densities which will maximize fiber production, and therefore stand vigor, using yield simulation models as guides. Eradicate infected stands by clear-cutting and regenerate artificially when simulation models indicate that they will not reach maturity because of mistletoe." (U.S. Department of Agriculture 1985).

Any conflicts in the standards and guidelines need to be identified and addressed during this initial stage of project planning. For example, conflicting guidelines may exist for visual management and dwarf mistletoe management.

The next phase in the IRM process is to develop the project concept. The objective is to determine precisely what this project will be designed to do and why. This is done by identifying the site specific issues, concerns, and opportunities through initial scoping meetings of the ID Team, specialists and consultants, and interested publics. Project objectives are then developed to accomplish the opportunities, mitigate the concerns and resolve the issues.

Site specific public issues for the Meads Timber Sale were identified during public meetings. These included concerns about mistletoe infestation surrounding private land, and types of slash treatments. Forest Pest Management specialists participated in developing the project concept by providing pest related management concerns and opportunities. One of the management concerns for the Meads Timber Sale was managing timber resources with the adverse combination of a narrow age class distribution, multi-storied stand structure, and severe dwarf mistletoe infestation. Opportunities included treating dwarf mistletoe through harvesting and post-sale treatments, improving age class diversity, and educating the public on IRM, silvicultural practices, and mistletoe control.

The objectives developed for the Meads Timber Sale included managing the timber resource through silvicultural treatments to promote growth and reduce mortality, generating sawtimber, pulpwood, and fuelwood for public and commercial utilization, managing for improvement of wildlife habitat and watershed conditions, and reducing fire hazard by treating fuels. The activities proposed were timber harvest, residue disposal, reforestation, thinning, forage production, and wildlife habitat and watershed improvement.

ANALYSIS

One of the most critical phases of project preparation is intensive reconnaissance. Members of the ID Team and other specialists assemble or collect all of the site specific information needed to design a project that suits its unique location and objectives. Attempts are made to interrelate the various resources which exist within the area. The entire ID Team and consulting specialists may visit the project site to verify and refine the issues, concerns, and opportunities identified in the earlier phases and to identify project design specifics.

Analysis of silvicultural treatment needs actually begins earlier in the project planning process. Silvicultural treatment diagnoses are prepared following detailed stand examinations. Results of these exams are detailed descriptions of stand structure and composition and pest incidence and severity. Stand exams for the Meads Timber Sale were supplemented by FPM funds in 1985 to collect more intensive data on dwarf mistletoe infested stands. The silviculturist then prepared a diagnosis of treatment needs for each stand in the assessment area. The diagnoses defined individual stand objectives, described present stand conditions, and proposed treatments to develop conditions that would best satisfy the objectives. Stand priorities for treatment were developed to rank stands within the assessment area. High priority stands were multi-storied with dwarf mistletoe infection in the overstory that could infect an adequately stocked understory. Medium priority stands were mistletoe-infected, even-aged stands where the disease could be controlled through silvicultural treatment. Low priority stands were those where dwarf mistletoe was not a problem and regeneration was not diagnosed.

A separate, more intensive survey was conducted in 1988 surrounding the private lands within the Meads Timber Sale Area. The objective was to identify areas where silvicultural treatment could prevent spread of dwarf mistletoe onto or from private lands. Pest specialists from Arizona State Forestry Division worked with landowners in the residential developments to encourage treatment of dwarf mistletoe on private lands.

Forest Pest Management was involved in the reconnaissance phase of analysis for the Meads Timber Sale by visiting specific stands within the assessment area with the silviculturist to discuss diagnosed treatments to deal with the dwarf mistletoe problem. A biological evaluation was prepared to ensure that the proposed treatments were biologically sound and that they met the dwarf mistletoe management objectives identified earlier. Alternative ways of treating uneconomic stands were discussed, such as funding sanitation thinning with FPM pest suppression funds or sale area improvement funds.

The next phase in project planning is alternative generation and comparison. The objective is to develop and compare a reasonable range of alternatives including a "No Action" alternative. Specific alternatives to deal with pest situations may be developed by the ID Team. Since the priorities for silvicultural treatment for the Meads Timber Sale did not change by alternative, all the action alternatives considered dwarf mistletoe management to some degree. Alternative 1 treated selected stands that met the following criteria: 1) high or medium silvicultural treatment priority, 2) dwarf mistletoe infection of ponderosa pine, and 3) economic to harvest based on projected road construction costs. Alternative 2 treated selected stands that were: 1) high or medium silvicultural treatment priority, and 2) dwarf mistletoe infected regardless of economic feasibility. Alternative 3 treated all stands identified in Alternative 1 along with a priority list of potential stands that would become feasible as small salvage sales with supplemental funding. Alternative 4 was the "No Action" alternative.

The next phase of IRM is to compare and evaluate alternatives with respect to environmental effects, accomplishment of project objectives, and economic feasibility. Evaluation criteria for comparison of alternatives may include some measure of pest suppression or prevention, such as, acres treated for mistletoe or acres with reduced bark beetle hazard. Alternative 4 (no action) for the Meads Timber Sale would have prevented opportunities for wildlife habitat and range improvements, fuel management, and visual enhancements. The effects of no action would be further deterioration of forest health due to intensification and spread of dwarf mistletoe. Alternative 2 would treat the most acreage of timber with mistletoe infection and produce the most volume but it had the highest road cost per timber volume removed. Alternative 3 would treat the same acreage if all additional potential stands were funded. The supplemental treatment of mistletoe in Alternative 3 would provide the best benefit for visual quality by prevention of mistletoe spread and subsequent mortality. The ID Team recommended that Alternative 3 be the preferred alternative. This alternative would achieve an economical sale, provide for the most acreage of mistletoe treatment, improve age class diversity, and provide an opportunity to treat mistletoe infestation and manage fuels around private lands.

DOCUMENTATION

The responsible official selects the preferred action from a range of alternatives and determines appropriate NEPA documentation to fully comply with regulations. Pest management documents or information may need to be included or referenced in the NEPA documentation. An Environmental Assessment was prepared for the Meads Timber Sale. The Forest Supervisor determined that this was not a major action that would significantly affect the quality of the human environment and, therefore, an environmental impact statement was not needed. In the Decision Notice the Forest Supervisor stated that the preferred alternative was Alternative 3 because it provided for an economically viable sale that treated the most acreage of dwarf mistletoe, improved conditions for future timber production, and improved the age class diversity which benefits wildlife.

IMPLEMENTATION

During the preparation of project action plans, FPM specialists provide assistance in project layout and development of contract provisions. For example, special contract provisions may be required for low elevation ponderosa pine stands to prevent infestation by Ips bark beetles. These provisions may call for utilization of trees to a 4 inch top, limiting cutting to specific seasons (July to December), or requiring prompt removal or treatment of suitable brood material (Parker 1979). Forest Pest Management specialists may also be involved in field review of final silvicultural prescriptions, cutting unit layout, and timber marking guidelines.

Unexpected circumstances during project implementation may require modification of the action plan with input from FPM specialists. For example, abnormally dry conditions may increase risk of bark beetle infestation.

MONITORING

Once the project is completed FPM specialists assist in monitoring project effectiveness. Post treatment evaluations are conducted to determine if project objectives were met. Evaluation results are used to modify or improve pest management strategies for future projects.

CONCLUSIONS

The Meads Timber Sale provides an example of how pest management can be incorporated into the development of a timber sale. The IRM process is also utilized to provide pest management input into other types of projects. Forest Pest Management specialists have participated in the development of new recreation sites where forest pests are a concern. Surveying of proposed sites prior to design and development is the best way to avoid future problems. For example, surveys of a proposed campground may reveal pockets of root disease that should be avoided to reduce tree mortality and hazard to recreationists. Forest Pest Management specialists have also provided input to ID teams analyzing ski area expansion, salvage sales following burns, and wilderness area management.

In the Southwestern Region, we are working toward incorporating pest management considerations into project plans through the IRM process. By being involved in all phases of IRM, from the initial development of project concepts to the eventual implementation and monitoring of success, Forest Pest Management is insuring that pest effects are considered in land management decisions. Hopefully, this will help us leave a healthier forest than we inherited.

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Effects of Controlled Grazing of Understory Grasses and Forbs on Survival and Growth of Ponderosa Pine Seedlings[1]

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Abstract--A case history of Piney Burn on the Navajo Reservation in northeast Arizona is described. The man-caused fire which occurred in 1977 encompassed 145 ha. In the following year, a regeneration project was established with containerized Ponderosa pine seedlings. Concern over accelerated erosion prompted a decision to also aerially seed adapted grasses and forbs. The subsequent failure of the plantation was attributed to competition from the grass-forb understory. Another reforestation project was initiated in 1981. After three growing seasons, surveys indicated that competition from the understory was seriously inhibiting conifer growth. Experimental trials in 1985 were implemented that utilized randomized block designs on twelve (12) plots to evaluate the effects of manual scalping, herbicide (low rate), herbicide (high rate) and control treatments on survival and growth of pine seedlings. Mechanical defoliation significantly enhanced ($P=<0.05$) both height and diameter of seedlings in the first growing season. Chemical defoliation increased only height ($P=<0.05$). Concurrently, heavy grazing by cattle in two 0.8 ha enclosures effectively reduced vegetative competition and caused only about one percent conifer mortality.

During 1986-89, the entire area was divided into three units to investigate grazing effects on conifer canopy, density, height and diameter. The treatments were: no grazing, moderate grazing in alternate years and moderate grazing in consecutive years. These treatments were not replicated. However, the data suggest that highest grazing frequency was associated with greater values for canopy cover and the growth parameters, height and basal diameter. Density of conifer seedlings was apparently not enhanced or reduced by grazing treatments.

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INTRODUCTION

In their respective professional sectors, livestock production and timber regeneration were perceived as mutually exclusive for many years. These perceptions were based on histories of overgrazing by domestic livestock on many Southwestern forests. Uncontrolled grazing has frequently resulted in trampling, browsing and the ultimate mortality of young conifers. As intensity and duration of livestock use increases, the likelihood of conifer browsing becomes greater because more palatable forages are eliminated. These conflicts are especially extreme on Ponderosa pine forests of the Navajo Reservation where competition for resources becomes more intensified with each generation. In the latter locale, grazing by several classes of livestock has continued without restrictions for more than one hundred years, often to the extreme detriment of Ponderosa pine regeneration.

In other areas of Ponderosa pine-bunchgrass ranges, voluntary restrictions are enforced by recognition of the toxicological effects of pine needles in cattle. The primary effects are abortion and associated complications (Panter and James 1987). Risks of these effects can be minimized by intensive management. The incidence of abortion is most high when pine needles are ingested close to the time of normal parturition. Most of the abortions in cows eating pine foliage generally occur in the late fall, winter or early spring, the period that corresponds to the third trimester of pregnancy. The factors that are believed to cause pregnant cows to browse pine needles include stress, lack of familiar or high quality feed, sudden access to pine needles (e.g., windfalls), boredom or curiosity and accidental ingestion with other feed. Most managers and stockgrowers, however, believe that Ponderosa pine-bunchgrass ranges can be safely grazed if timing and intensity of use are closely monitored.

Figure 1.--Grass-forb understory on Piney Burn resulting from aerial seeding inhibited establishment and growth of conifer seedlings

Recently, the use of domestic livestock as biological agents for control of unwanted vegetation has increased because of the obvious economic and environmental benefits of these procedures (Hedrick 1975; Wood 1987). A biological agent is described by Brock (1988) as an "organism that has an action leading to the destruction of another organism (host) or weakens it so that pathogens attack it or make it competitive with other organisms...". Sheep and goats are the most common domestic biological agents. Cattle generally have a lesser potential for biological control because forbs and shrubs that are commonly regarded to be pest species are not preferred constituents of their diets. One considerable advantage of prescribed livestock grazing over chemical or mechanical controls is that unwanted, competitive vegetation may be removed while marketable animal products are simultaneously produced (Sharrow et al. 1989). This advantage is contingent upon two conditions being met: (1) livestock must utilize the unwanted vegetation while not significantly damaging the commercially valuable species, and (2) target species must not regrow substantially after grazing/browsing.

The most recent technical literature reports growing evidence that prescribed or controlled livestock grazing can be successfully used to promote establishment and growth of conifer seedlings when numbers, distribution and timing of use can be strictly controlled. Doescher et al. (1987) caution that the following factors must be observed when livestock are used to suppress competing vegetation: (1) palatable forage must be available to minimize conifer damage, (2) when moisture is limiting, vegetation should be grazed before stored soil moisture is depleted, (3) animal numbers and their distribution must be controlled to reduce browsing and trampling damage, and (4) costs of a grazing program must be minimized.

On young conifer plantations, maximum reductions in the plant vigor of understory vegetation can be achieved by reducing the carbohydrate reserves during periods of active growth. These reserves reach their lowest levels shortly after plants initiate shoot elongation. When grazing corresponds to this period, plant vigor and carbohydrate reserves of competing vegetation can be substantially reduced. Controlled grazing by domestic livestock or conifer plantations has had widespread applications in the last few years.

METHODS AND CASE HISTORY

Phase I (1977-85)

The study area resulted from a man-caused fire which occurred in 1977 known as the Piney Burn. It encompasses an area of 145 ha on the Defiance Plateau approximately 6 km southwest of Sawmill, Apache County, Arizona at an elevation of 2485 m. A salvage cut was conducted in the fall of that year to recover harvestable but damaged timber. In late spring, a large portion of the

burn was fenced and containerized Ponderosa pine seedlings were planted at a rate of 1683 seedlings per ha. Later that season, concern over surface erosion precipitated a decision to aerially seed adapted exotic and native grasses onto the burn. The results of that seeding were unusually successful to the extent that the subsequent failure of the reforestation project was attributed to grass-forb competition. The surface was later disked to prepare the seedbed for other plantings in 1981-2. A second planting of containerized seedlings was completed during that period, with the largest segment (100 ha) being planted in August, 1981. In each of the next three successive growing seasons, surveys were performed to monitor survival. The 1984 survey indicated that various environmental stresses were inhibiting Ponderosa pine seedling growth and reducing survival (Thomas 1986). The primary stressor identified by the survey was the high level of competing vegetative ground cover. Approximately 67 percent of the reforested area was covered by competing vegetation consisting mostly of exotic and native grasses. Management alternatives initially considered to reduce this competitive effect were prescribed grazing, manual scalping and herbicide applications.

In the spring of 1985, twelve (12) 0.025 ha plots were situated on the plantation at random coordinates. Each replication contained four subplots (0.00625 ha) measuring 15.8 X 15.8 m. The configuration of subplots within each replication was determined by a randomized block design. Treatments applied to each plot were as follows:

(1) Untreated.
(2) Manual scalping. Surface vegetation within a 0.6 m radius of seedling was removed using hand tools.
(3) Herbicide (low intensity). Surface vegetation within a 0.6 m radius of pine seedlings was sprayed with Velpar L at a rate of 5 liters + 1450 liters water + surfactant (detergent)/ha.
(4) Herbicide (high intensity). Surface vegetation within a 0.6 m radius of pine seedlings was sprayed with Velpar L at a rate of 10 liters + 1450 liters water + surfactant/ha.

Seven seedlings in each subplot were selected for measurement by rotating a tape from the center and marking the first seedling encountered at each 51 degree interval. Included in the collected data were density/subplot, mortality/subplot, cover by competing vegetation and growth parameters (height and stem diameter) of the selected seedlings.

Data were subjected to comparative analysis via the Anova 9 program modified for use on the Burroughs B21.4 computer. When the analysis of variance indicated F-values with significant levels of difference among means ($P=<0.05$), Duncan's Multiple Range Test was employed.

Concurrently, grazing trials were conducted within two (2) 0.8 ha enclosures measuring 90 X 90 m. Livestock were confined by solar-powered electrical fence for two periods of 24-30 animal days in order to obtain a heavy level of utilization. Twenty-eight (28) seedlings were selected for monitoring in each enclosure by rotating clockwise a tape stretched due north from points on a systematic grid. Data collected from these plots were the same as for the defoliation plots but direct comparisons were not made because of inherent design differences.

Figure 2.--Heavy grazing in enclosures (right of photo) suppressed vegetative understory with minimal damage to pine seedlings.

Phase II (1986-1989)

The Piney Burn plantation with approximately 70 percent evenly distributed survival, was certified successful in 1986. In that year, a decision was made to expand the grazing trials to include the entire plantation. The 145 ha area was divided into three pastures by electrical interior fences. The three treatments were as follows:

(1) Ungrazed by domestic livestock.
(2) Moderately grazed in alternative growing seasons (1987 and 1989).
(3) Moderately grazed in consecutive growing seasons[3].

Moderate grazing was considered to be utilization less than 50 percent of the above ground biomass, excluding wood species. That level of use was consistent with the work of earlier researchers (Currie 1975; Clary 1975) who recommended that 30 to 40 percent utilization and 30 to 38 percent utilization, respectively, were the optimum levels of use for Ponderosa pine-bunchgrass ranges. They suggested that levels of use greater than 50 percent could result in reduced animal production and potentially long

[3] Logistical problems occurred in 1988 and prevented placement of cattle into the plantation. Therefore, this subunit was grazed in 1986, 1987 and 1989, but not in 1988.

Table 1. Vegetative cover in percent (%) during 1985 growing season in twelve (12) measured plots.

	Before Treatment	After Treatment		
	May 16	June 19	July 31	Sept. 23
Treatment				
Untreated	72.5[a]	73.8[a]	76.3[a]	77.1[a]
Manual Scalping	71.9[a]	60.4[b]	61.7[c]	64.2[b]
Herbicide (low rate)	70.8[a]	69.6[a]	73.8[ab]	74.2[a]
Herbicide (high rate)	70.8[a]	68.8[a]	70.0[b]	72.9[a]

[a,b,c]Within columns, mean values followed by the same superscript are not significantly different (P=<0.05).

term damage to the range. Use levels were closely monitored each summer until the approximately 40 cattle introduced to the units had achieved desired levels of consumption. Data collection was deferred until Fall, 1989. Since the plantings had been made in three stages, the data collection was limited to the largest segment (100 ha planted in August, 1981) to eliminate possible differences resulting from age.

Within each of the three treatments, ten 100 m line transects were established at random coordinates. At the terminus of each transect, a 15 X 20 m quadrat was situated. Data collected at each site were as follows:

- canopy intersect (cover)
- density
- basal diameters
- heights.

Canopy intersect was obtained by measuring the aerial cover of Ponderosa pine over a 100 m tape; all seedlings rooted within the quadrats were counted and measured to determine density, diameter and height. Analysis of variance was not performed on these data because the treatments were not replicated. Mean values, however, were tested using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Phase I

Understory vegetation growing in subplots was significantly decreased by manual scalping (P=<0.05) but not by either level of herbicide application. The high rate of herbicide produced a temporary reduction in ground cover which was not sustained by season's end. The low rate of herbicide application did not produce either temporary or sustained reductions in vegetative cover. These results are displayed in Table 1.

Although the mechanical technique effectively reduced vegetative cover temporarily, it was extremely labor intensive and costly. Larson and Schubert (1969) have advised that Ponderosa pine should only be planted on completely grass-free areas. Complete site preparation involving killing or removing grasses was seen as the best

Table 2. Growth parameter increases in percent (%) during 1985 growing season on twelve (12) measured plots.

Treatment	Stem Diameter	Height
Untreated	+9.9[a]	+16.1[a]
Manual Scalping	+16.2[b]	+20.1[b]
Herbicide (low rate)	+16.2[b]	+16.3[a]
Herbicide (high rate)	+16.0[b]	+16.8[a]

[a,b]Within columns, mean values followed by the same superscript are not significantly different (P=<0.05).

Table 3. Vegetative cover in percent (%) in two grazing enclosures during 1985 growing season.

Enclosure	Before Grazing	After First Grazing Cycle	After Second Grazing Cycle	End of Growing Season
Unit 1	70.2[a]	65.3[b]	59.5[c]	61.1[c]
Unit 2	69.9[a]	66.8[ab]	64.8[b]	64.8[b]

[a,b,c]Within rows, mean values followed by the same superscript are not significantly different (P=<0.05).

condition for the survival and growth. Partial site preparation was considered to be inadequate and not suitable for Southwestern plantations.

The growth parameters of Ponderosa pine seedlings were affected by defoliation treatments. Manual scalping and both levels of herbicide application produced significantly greater (P=<0.05) increases in basal diameter. Manual scalping, however, was the only treatment producing greater height (Table 2).

In the two grazing enclosures, vegetative cover was significantly reduced (P=<0.05) after two grazing periods (Table 3). No grazing damage to pine seedlings was observed in spite of concentrated, heavy utilization of the grass-forb understory. Some trampling damage to seedlings did occur when cattle were left overlong in the enclosures but damage was light to moderate and within acceptable levels. Seedling mortality in the enclosures was very low. Mortality rates, based on total seedlings/unit, were 1.28 percent and 1.01 percent in Units 1 and 2, respectively. Mortality, when it occurred, was primarily attributed to trampling and bedding.

Phase II

The data collected in October, 1989, on the three larger grazing units are shown in Table 4. The inability to incorporate replications of treatments in these trials disallows inferences about direct results of grazing. There are, however, certain trends indicated by the data.

The data do not indicate differences in density of seedlings between treatments. This suggests that grazing by cattle has not resulted in increased pine mortality. The highest cover (canopy) values were found in the treatment receiving the most frequent grazing use. The highest values for growth parameters, both height and basal diameter, were also found in the unit receiving the most intensive treatment.

These results are consistent with other recent studies which have employed livestock as biological agents to reduce competitive understory. In California, cattle graze mixed conifer plantations each year during the June 1-September 30 period (Kosco and Bartoleme 1983). Grazing treatments on clearcuts indicate that cattle do not harm tree regeneration on these plantations. No trampling damage was reported and browsing did not make any differences in overall tree seedling height or basal diameter between treatments. Sharrow et al. (1989) report that sheep grazing in the Pacific Northwest successfully suppressed competing vegetation on conifer plantations. The reduced understory biomass on grazed plantations was consistently associated with greater (P=<0.05) diameter growth of Douglas fir seedlings. Three

Table 4. Mean values on three grazing units after four years of treatment (1989).

Treatment	Cover (%)	Density No./Plot	Mean Height (cm)	Mean Diameter (mm)
Ungrazed	2.056[b]	32.8[a]	59.9[b]	27.8[b]
Grazed 2 of 4 years	1.200[b]	25.6[a]	55.2[b]	26.0[b]
Grazed 3 of 4 years	3.905[a]	33.0[a]	70.2[a]	32.7[a]

[a,b,c]Within columns, mean values followed by the same superscript are not significantly different (P=<0.05).

seasons after the cessation of grazing treatments, trees in grazed plantations were approximately 5 percent taller ($P=<0.05$) and 7 percent greater ($P=<0.01$) in diameter (DBH) than trees in ungrazed controls. Pearson (1987) reported that 5 year old pines in Southern plantations were 1.5 feet taller on grazed vs. ungrazed sites. No significant differences in seedling survival were noted. On grazed vs. ungrazed plantations in eastern Oregon investigated by Krueger (1987), height growth of planted Ponderosa pine trees was 10 to 17 percent higher and diameters were 9 percent greater. In stands of Douglas fir in Oregon, Hall et al. (1959) reported that cattle effectively removed palatable grasses and reduced fire hazards without damage to the establishment and growth of tree seedlings. Finally, in Colorado, Currie et al. (1978) found that light to moderate stocking rates of cattle resulted in negligible damage to both artificial and natural regeneration in Ponderosa pine-bunchgrass ranges.

CONCLUSIONS

Established grass-forb understories can seriously suppress the establishment and growth of Ponderosa pine plantations. Such stands continue to inhibit conifer growth, primarily through competition for soil moisture, for many years after planting. Mechanical and chemical defoliation of the immediate understory can provide temporary advantages to pine seedlings but these applications are costly and labor intensive. Moreover, there is no available evidence that advantages to conifer seedlings are more than short-lived.

The most cost-effective strategy presently available for suppressing understory grasses and forbs is the use of livestock as biological agents. In the case study of Piney Burn, cattle were the biological agents employed. When utilization was restricted to a moderate level, cattle were introduced in the active growing season only and grazing was imposed annually, the following advantages were perceived:

(1) Fire hazard was substantially reduced because available fuel was diminished.

(2) Negligible mortalities of pine seedlings resulted from cattle activities.

(3) A collateral use (grazing) of Ponderosa pine plantations was shown to be financially, as well as biologically, beneficial.

(4) This and other reported studies indicate that grazing may enhance growth and development of conifer seedlings by suppressing competition.

(5) The same physical facilities constructed to protect timber regeneration can facilitate controlled grazing by livestock.

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Effects of Prescribed Springtime Underburning on Production and Nutrient Status of a Young Ponderosa Pine Stand[1]

Charles C. Grier[2]

Abstract.--The effects of prescribed fuel-reduction fire were examined experimentally in a 43-year-old *Pinus ponderosa* Laws. stand in north central Washington State. The stand had been precommercially thinned 14 years before this study. Competitive mortality indicated residual trees had fully reoccupied the site. Treatments were: unburned control, light burn (existing fuel load of ≅ 30 Mg ha^{-1}) and heavy burn (fuel added to total 85 Mg ha^{-1}). Relative to before-fire values, pine fine root biomass (<2 mm diameter) in the top 5 cm of soil had increased 50% on the control plots, stayed the same on the light burn plots and decreased 63% on the heavy burn plots when measured two weeks after the fire. Needle litterfall in the control plot during the year after burning was 0.66 Mg ha^{-1} while that on the light and heavily burned plots was 2.1 and 2.2 times control plot values. The amount of nitrogen and phosphorus returned in litterfall was 2- and 3-times control amounts on the light and heavy burn plots. Wood biomass increment of the burned plots was consistently about 10% greater than control before the fire. The year after burning, the light and heavy burn plots had wood biomass increment 66% and 52% of control values. Spring burning occurs when roots of trees are adapted to cold soils. Heat from fires was measurable at 10 cm and may have brought soil temperatures above the lethal temperatures for cold-adapted roots. Root mortality appears to have caused the observed changes in production and nutrient status.

INTRODUCTION

Relatively little is known about the fine root component of most forest ecosystems--even less is known of the impact of various forest management practices on this critical ecosystem component. There is no question that fine roots are an important part of an ecosystem; their role in water and nutrient uptake has long been well documented (Kramer and Kozlowski 1960). What is not generally appreciated is the investment a forest makes in maintaining its root system.

Previous studies in undisturbed forests have shown that fine root growth comprises a relatively large proportion of total forest productivity. Current estimates are that from 10% to over 70% of annual net primary production is utilized in maintaining the fine root system of forests (Harris et al. 1978, Persson 1978, Keyes and Grier 1981, Vogt et al. 1986). Factors influencing production and turnover of fine roots are not yet completely understood but the proportion of annual net production utilized for fine roots appears to be inversely related to site quality. Keyes and Grier (1981) studied fine roots dynamics in young Douglas-fir stands growing on contrasting sites. On a productive site, only 15% of net production was used to produce fine roots--for poor sites about 40% of net production was utilized for fine roots. In well-watered, highly productive coastal forests of Oregon, only about 10% of annual productivity is invested in fine root growth (Grier et al. 1986). Moreover, the amount of fine roots produced annually appears to increase as site productivity decreases. In productive western coastal forests, fine root production is about 2000 kg/ha/yr (Vogt et al. 1986) while comparable values for poor site Douglas-fir and low productivity subalpine forests are about 7000 and 10,000 kg/ha/yr, respectively (Vogt et al. 1986).

Fine roots also play an important role in nutrient cycling. In addition to their role in

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nutrient uptake, a substantial part of the ecosystem nutrient capital is invested in fine roots. For example, roughly 10% of the total nitrogen capital in the living part of a 30-year-old western hemlock stand on the Oregon coast was in the fine roots (Grier, 1976). Comparable values for poor-site Douglas-fir and low productivity subalpine silver fir stands are about 35% and 50% respectively (Keyes and Grier 1981, Grier et al. 1981).

Fine roots in most coniferous forests studied appear to be concentrated near the soil surface. In most coniferous forests where vertical distribution of fine roots has been quantified, over 80% of their biomass is shown to be in the upper 10 cm of soil. Of this 80%, about 60% to 70% is found in the upper 2-4 cm (Vogt et al. 1986). Thus, fine roots, which represent a significant portion of annual production and stand nutrient capital, are located in a position where they are vulnerable to a variety of forest management practices.

In Spring of 1979 I began a study of the effects of early-season fuel-reduction underburning on primary production and nutrient cycling in 45-year-old ponderosa pine stands. The basic premise was that, while ponderosa pine is a fire-adapted tree species, it is adapted to fires occurring late in the growing season, at least in the Intermountain region. Early season fires would occur when active root growth was in progress: heat conducted into the soil from early season fires would have the potential to damage or kill activity growing fine roots, consequently reducing productivity. These heat effects would be amplified by the high thermal diffusivity of moist soils and the low soil temperatures to which roots are adapted after winter. Late summer or early fall fires, on the other hand, occur when roots are inactive, soils are dry and thus good insulators, and roots are adapted to higher soil temperatures.

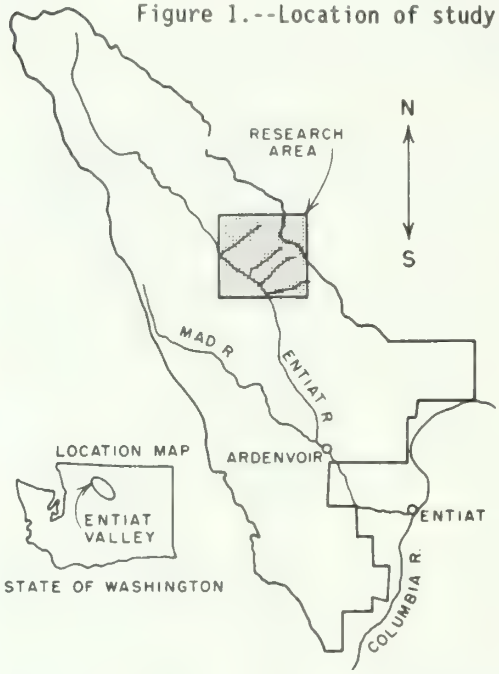
The objective of the research described in this paper was to investigate the possibility of fine root mortality occurring as a result of spring underburning in ponderosa pine stands on the east slope of the Washington Cascade Mountains. Specific objectives of the study were to: 1) determine the amount of fine root mortality resulting from fires in average and heavy fuels; 2) determine the changes in productivity, if any, resulting from fire-caused root mortality, and 3) determine the changes in nutrient distribution in stands subjected to underburning.

Results of this study should provide answers to questions regarding the influence of underburning on forest productivity. Moreover, information obtained from his research should enable the forest manager to use residue reduction fires in such a way as to minimize both short-term losses in forest productivity and the potential for invasions by root pathogens.

RESEARCH AREA

The study was conducted in a ponderosa pine stand located at Johnson Creek Summit, Entiat Ranger District, Wenatchee National Forest (Fig. 1).

Figure 1.--Location of study area.



The area is located in Section 6, T26N, R21E; Section 25, T27N, R20E and Sections 30 and 31, T27N, R21E, Willamette Meridian. The stand was about 45-years old at the time of burning in 1979. The stand had been precommercially thinned in 1967 to about 500 stems per hectare. Slash was lopped and scattered. Vegetation consisted of a dominantly ponderosa pine (*Pinus ponderosa* Laws.) overstory containing scattered Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) with a mixed grass-sedge understory. Stand characteristics are given in Table 1. Soils in the study area were Inceptisols formed in Swankane gneiss overlain by 10 to 20 cm of Glacier Peak volcanic ash (Wilcox 1965). The site is nearly level with an average annual precipitation of about 50 cm. July temperatures average about 18°C while January temperatures averaged -1°C.

The 50 m square plots were established in: 1) an unburned control area, 2) a light fuel burn plot representative of the average fuel loading in the area of 30 metric tonnes/hectare, 3) a heavy fuel burn plot in which fuel was added to approximate areas of heavy slash accumulation (85 t/ha) over the entire plot.

Burning was conducted on May 29, 1989. Burning was prescribed by and conducted under the supervision of Charles Wolf, Fire Management Officer, Entiat Ranger District, Wenatchee National Forest. The burning objective was to

Table 1.--Characteristics of research stand, Johnson Creek Summit, Entiat R.D., Wenatchee N.F.

Species:	PIPO - PSME
Location:	Johnson Cr. Entiat R.D.
Elevation (m.):	930
Density (stems ha^{-1})	450
Basal area (m^2 ha^{-1})	
1967	11.9
1979	19.7
1987	25.0
BAI (m^2 ha^{-1}) $year^{-1}$)	0.4
Age (yr.)	58
Fuel load (tonnes ha^{-1})	
Thinning slash	11.2 - 78.4
Forest Floor	22.4
Prescribed burn	29 May 1979

achieve a fuel loading of "MM" over the study area.

METHODS

Burning was conducted by USFS personnel. Two intensities of fire were examined, intensity here being defined in terms of fuel loading. The light burn was conducted at the existing fuel loading (Table 1) while the heavy burn had fuel such as branches and foliage added to equal a loading of about 95 to T/ha.

A vegetation survey utilizing methods described by Daubenmire (1968) was conducted to assure that plots were representative of the overall forest type.

Sampling of the fine roots was conducted immediately before the burn and immediately after the burn. A total of 12 - 4 cm diameter, randomly located soil cores were taken to a depth of 15 cm from each plot at each sampling. In practice, this gave an estimate of live fine root biomass of ±15% at the 90% confidence level. Local fire severity at each sampling location was noted to aid in stratifying samples if necessary.

Fine roots were separated in the laboratory into those from the upper 5 cm of each soil core and those from 5 to 15 cm; this was done to facilitate detecting any mortality response to surface heat. Roots from all samples were additionally separated into the 0-2 mm, 2-5 mm, and >5 mm. size classes. All roots were dried at 70°C for 48 hours, then weighed. Weights were corrected for adhering soil particles by ashing samples of dried roots in a muffle furnace and computing a correction factor which was applied to the dry weights to compute biomass.

Diameters of all trees in each plot were measured to the nearest 0.1 cm. Increment cores were taken from each tree in fall of the year of burning. These data plus those from litterfall measurements were used to estimate above ground.

Productivity changes were estimated from annual litterfall collections (dry wt. - 70°C) and growth ring analysis. In the latter case stand biomass increment was calculated using published biomass regressions on stem diameter for ponderosa pine (Gholz et al. 1979).

Eight, 0.25 m^2 litter screens were installed on each plot. Samples were collected one month after the burn and every six months through 1982. Samples were sorted into two categories: foliage and other material. We anticipated increased leaf litterfall as a result of fire. This procedure provided a simple measure of its magnitude.

Soil samples were obtained from soil cores after the live roots were removed. Each sample was a composite of four samples from the two root sampling layers. Roots were also sampled and bulked to give 3 samples per horizon for each plot. These samples were used for determinations of percent ash, N and P. This part of the study (not yet completed) will aid in detecting changes in nutrient availability. Current years and older foliage, current years twigs, branches, stemwood, stembark and litter samples were also subjected to chemical analysis. Details of analysis are given by Grier 1976.

Heat sensors were constructed from Templaq® paints and Tempilstik® crayons on asbestos sheet. These were installed at the soil surface and at 2.5 cm and 10 cm below the surface to determine the soil temperature profile beneath each burn. Twenty sensors were used at each level on each treatment. Sensors covered the temperature range from 40°C to 200°C in roughly 20°C intervals. Additional temperature measurements were made during burning at the 10 cm depth using a recently calibrated dial thermometer to measure temperatures.

RESULTS AND DISCUSSION

The prescribed fire effectively reduced fuel loadings in the study stand. Table 2 shows the reduction in surface fuels resulting from the fire.

In addition to the 70 to 90% reduction in forest floor and thinning slash, stumps remaining from the pre-commercial thinning were also burned. Burning raised temperatures in soils of the treatment plots (Table 3) even at the 10 cm depth.

Soils were near field moisture capacity at the time of burning. For this reason, thermal diffusivity of the soils was high and

Table 2.--Pre- and post-fire surface fuel loads for Johnson Creek Summit study plots.

Control	Light	Heavy
	Pre-Burn (T ha^{-1})	
33.6	33.6	93.2
	Post-Burn (T ha^{-1})	
33.6	10.1	6.7
	Fuel Reduction (%)	
0	70.0	92.9

evaporative cooling at the surface probably reduced soil heating. Temperatures measured here were low relative to those measured in many other prescribed fires (Grier 1972). However, increased temperatures were observed deeper in the soil profile than when soils were drier (Grier 1972).

In spite of relatively low soil temperatures, burning caused measurable change in fine root production in the treatment plots. Figure 2 shows pre- and post-burn fine root biomass of ponderosa pine in the 0 to 5 cm, and 5 to 15 cm layers of root biomass in the plot.

Table 3.--Peak temperatures (°C) reached in soils of treatment plots during fuel-reduction underburn. Johnson Creek Summit study plots Entiat R.D., Wenatchee National Forest.

Depth (cm)	Control 1/	Light Fuel	Heavy Fuel
0	8	60 2/	180 2/
2.5	6	40 2/	100 2/
10.0	5	20 3/	40 3/

1/ Measured at noon 28 May 79

2/ Peak temperatures during fire were measured using Templac® and Tempilstik®. Temperatures were greater than values listed, but below the next step. Steps were about 20°C apart.

3/ Measured with dial thermometer about 10 min. after the flame front had passed, 6 locations per treatment.

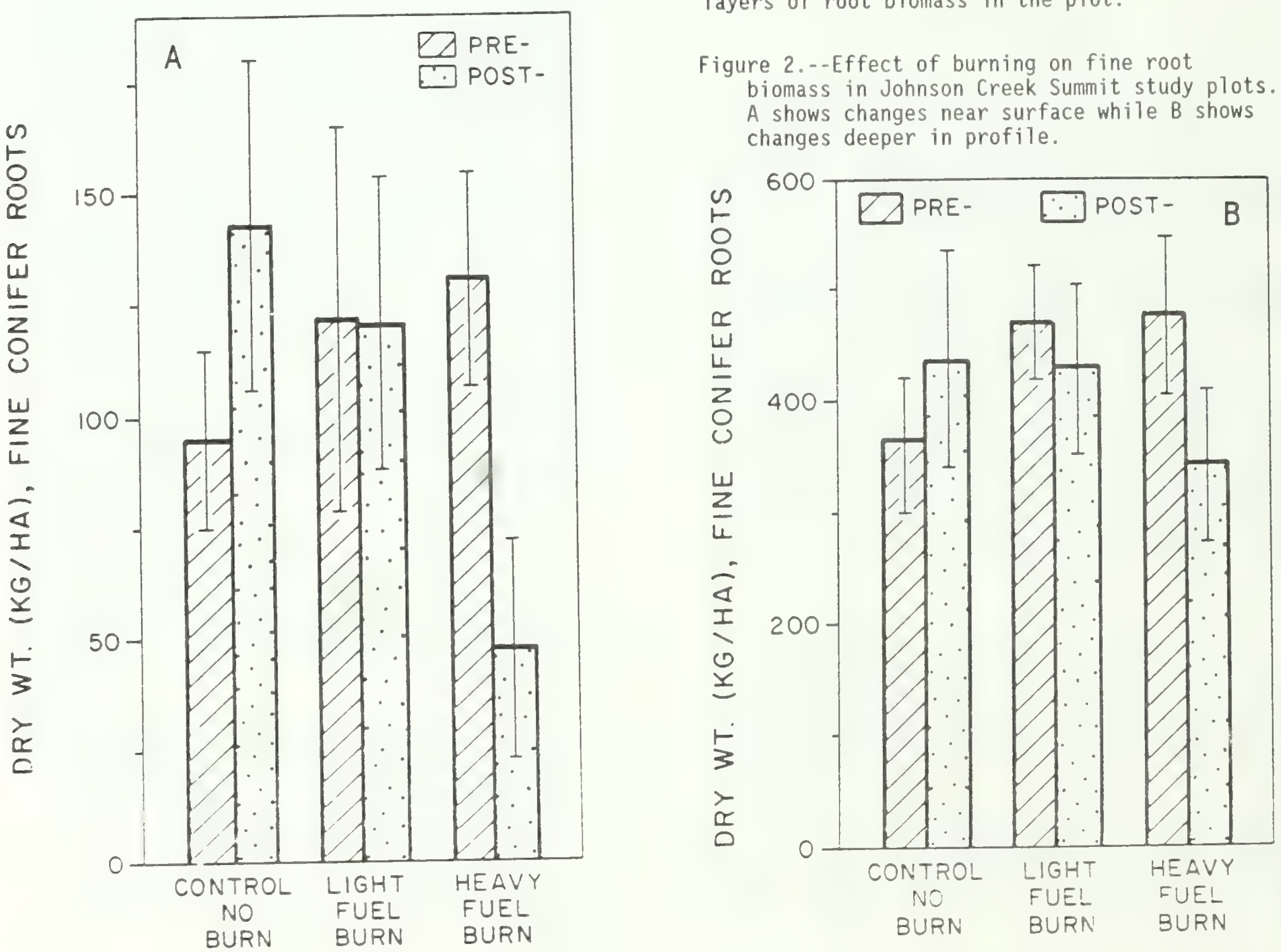


Figure 2.--Effect of burning on fine root biomass in Johnson Creek Summit study plots. A shows changes near surface while B shows changes deeper in profile.

Control plot fine root biomass increased over the interval between samplings. This increase was probably the normal spring flush of fine root growth. In contrast, fine roots in the light fuel burn showed essentially no change between samplings, while there was a 60% reduction in live fine root biomass in the interval in the heavy fuel burn. Reduced surface root production in the light fuel burn probably resulted from either heat injury to roots or the release of nutrients from the ash layer reducing the need for root growth. Fertilization has been shown to reduce root production in Douglas-fir (Grier et al. 1986) and the same response probably occurs in ponderosa pine. Reduction in fine root biomass in the heavy fuel burn is almost certainly due to heat injury.

The same trends in fine root biomass are apparent in the 5 to 15 cm layer of soil (Fig. 2) though they are somewhat muted by distance from the source of heat.

Figure 3 shows stemwood biomass increment for four growing seasons including 1979, the year of burning.
It is apparent that 1979 was a poor growth year for all treatments but reduction in growth as a percent of the mean for the three previous years, was much more severe for the burned plots (light fuel - 50% reduction, heavy fuel - 66%) than for the unburned plots (29%). The biomass increment reduction in the light fuel burn tends to rule out nutrient release as a factor in the suppression of root growth noted on these plots. Reduced root production in response to fertilization is generally accom- panied by increased wood production (Grier et al. 1986). Trees in the heavy fuel burn went from most productive to least productive of the three areas.

Needle litterfall on treatment plots was more than twice that on control plots (Table 4). On the light burn plot, this was probably due to the reduction in fine root biomass available to support a given level of foliage biomass. This, together with heat scorching of the foliage most likely caused foliage loss on the heavy fuel plots.

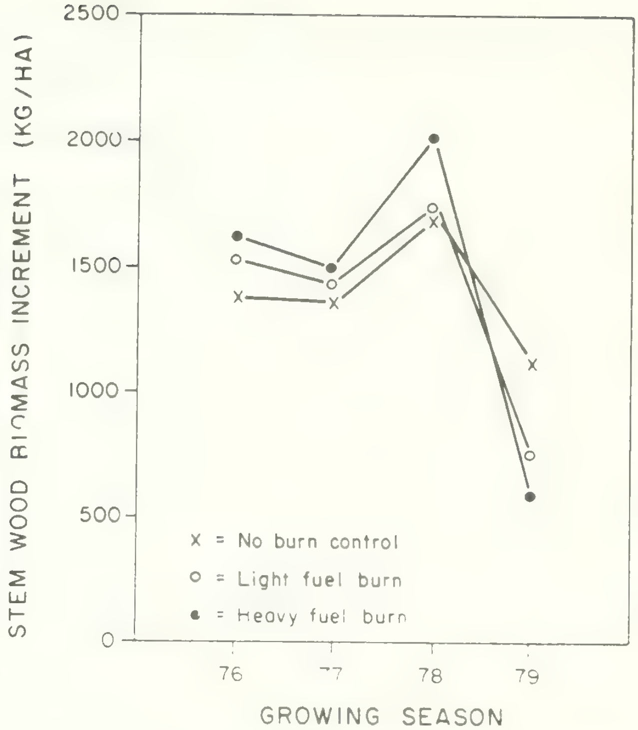


Figure 3.--Biomass increment on Johnson Creek Summit study plots after burning.

Concentration of nitrogen in needle litterfall from the burned areas was greater (5% in light fuels, 32% in heavy fuels) than in the unburned (Table 4). Trees in the burned plots thus lost more nitrogen (more than twice as much in the light fuel, almost three times as much in the heavy fuel) than in the unburned. Losses above those normally found in needle litter will have to be recouped before the stands in the burned areas can resume their pre-burn rates of production. Since both foliage and fine root biomass appear to have been set back, it seems reasonable to postulate further reduced production of stemwood increment for the next several years as photosynthate and nutrients are diverted to replacing lost foliage and roots. In fact, wood increment on the treatment plots was still below that of control plots eight years after burning (Table 5).

Table.4--Litterfall and litterfall nitrogen content from first year after burning on Johnson Creek Summit burn plots, Entiat R.D., Wenatchee National Forest.

	Needle litterfall kg/ha^{-1}	N %	N in needle litterfall, kg/ha^{-1}	N ratio (% of unburned)
Unburned	660	.393	2.58	1.00
Light fuel burn	1380	.414	5.70	2.21
Heavy fuel burn	1470	.520	7.64	2.96

Table 5.--Biomass increment (kg ha^{-1}) on Johnson Creek Summit fire plots: the 4-year pre-burn average, the year of burning for 1980 through 1987.

	(Burn) 1979	Avg. 74-78	1979 as % of 74-78	Avg. 70-98	80-87 as % of 74-78
Control	1370	1920	71.4	1800	93.8
Light fuel	910	1830	49.7	1640	89.6
Heavy fuel	710	2090	34.0	1390	66.5

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In Vitro Culture of Ponderosa Pine: Current Status and Future Prospects[1]

Yiqun Lin[3] and Michael R. Wagner[3]

Abstract.--The current status of knowledge about ponderosa pine (*Pinus ponderosa* Dougl. ex Law.) in vitro culture techniques for both juvenile and mature trees is presented. In vitro culture of ponderosa pine is at a very early stage of development compared with other gymnosperm species. Basic research on topics such as the mechanism of growth regulator effects on morphogenesis of cultures has received much less attention in ponderosa pine compared to other gymnosperms. Some techniques such as cell suspension culture and protoplast culture have not been applied to ponderosa pine. By devoting more effort to fundamental work and methods of in vitro culture, progress on ponderosa pine tissue culture will be greatly accelerated. We discuss the potential values and broad application prospects of in vitro culture in tree improvement programs of ponderosa pine.

INTRODUCTION

In vitro culture is defined as "the culture on nutrient media under sterile conditions, of plants, seeds, embryos, organs, explants, tissues, cells and protoplasts of higher plants" (Pierik 1987a). It is composed of the following techniques: 1) embryo culture, 2) organ culture, 3) cell suspension culture, 4) callus ture, and 5) protoplast culture. In vitro culture activities started in 1902 (Haberlandt 1902). The idea of in vitro culture started as a research tool to study factors affecting cell division and cell differentiation. In vitro culture technology served basic research for several decades. Not until the 1950's were in vitro culture techniques applied to agriculture and horticulture. With the rapid development of techniques and successful application to agriculture and horticulture, forest breeders and forest geneticists have been greatly attracted by in vitro culture techniques. Various woody species including angiosperms and gymnosperms have been propagated by in vitro culture techniques. These techniques for woody plants have proven to be of great value in mass propagation. Commercial production of several angiosperm species has been highly successful, such as *Eucalyptus* and *Populas*. It is reported that 100,000 plants may be produced from a single terminal bud of mature *Eucalyptus citriodora* Hook (cited by Haissig et al. 1987). In gymnosperms, more than 10 species have successfully produced plantlets. Among these species, *Sequoia sempervirens* (Lamb.) Engl. (Boulay 1987) and *Pinus radiata* D. Don. (Horgan 1987) have been commercially propagated.

The value of in vitro culture has not only been proven in mass propagation, but it has also been recognized as a tool in tree improvement programs. Its advantages compared with conventional breeding methods have been generalized as follows:

1) reducing the time of a breeding cycle;
2) rapidly increasing the number of propagules in a given time;
3) overcoming natural genetic barriers during the process of crosses;
4) conserving the gene pool and modifying germplasm.

For instance, Aitken-Christie et al. (1988) reported that one embryo of radiata pine could

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produce 5,480 pieces of meristematic tissue in 13.5 months. Each piece of meristematic tissue formed an average of 68.4 shoots. They estimated that in 2.5 years, 260,000 trees could be produced from a single, healthy embryo (Aitken-Christie 1987). Likewise, the susceptibility or resistance to the blister rust disease in seedlings or mature trees of *Pinus lambertiana* Dougl. can be examined in vitro in only 14 days (Diner and Mott 1982); whereas a routine progeny test would take much more time and energy. The in vitro culture technique has been more and more appreciated by forest breeders and geneticists. However, in vitro culture of ponderosa pine has just recently been initiated. In this paper, the current status of in vitro culture of ponderosa pine, its limitations, its future prospects, as well as its potential application to ponderosa pine tree improvement are discussed.

HISTORICAL REVIEW

In vitro culture of ponderosa pine began in 1969 (Harvey and Grasham). They used stem cortex of 3-5 year old ponderosa pine seedlings as starting material. The callus was obtained from the cortex tissue by applying Indole-3-acetic acid (IAA), Naphthalene acetic acid (NAA) and 2,4-Dichlorophenoxyacetic acid (2,4-D) at concentrations of 100, 500, and 1000 μg/l. NAA (500 μg/l) resulted in the best yield of callus. Recently, Tuskan et al. (unpublished) successfully induced shoots from embryo culture of ponderosa pine. The effect of growth regulators, basal media formula and carbohydrate levels which affect the explants growth and development, were tested. Schenk-Hildebrandt (SH) basal medium (Shenk and Hildebrandt 1972) with 4.4 uM Benzylamino purine (BAP) + 5.4 uM NAA and 1 sucrose was determined to be the best treatment for callus initiation. Callus was best maintained in the Linsmaier-Skoog (LS) medium (Linsmaier and Skoog 1965) with 44.0 uM BAP + 5.4 uM NAA and 2% sucrose. The best result of shoot formation was achieved in the modified Gresshoff-Doy (GD) medium (Gresshoff and Doy 1972) containing 44.0 uM BAP + 0.054 uM NAA and 4% glucose. Ellis and Bilderback (1989) reported the multiple axillary buds were formed in vitro from cotyledons of ponderosa pine. They tested the effect of BAP on the competence of multiple axillary bud formation of cotyledons of ponderosa pine. It was found that the presence of BAP is necessary for axillary bud formation of ponderosa pine cotyledons. An investigation of the effect of nutrient constituents on bud production from embryos was also performed (Ellis & Bilderback 1983, Bilderback & Ellis 1985). They found that bud formation was higher on half strength Cheng media (Cheng 1975) than on full strength. It is also found that dilution of vitamin concentration in SH media resulted in increased formation of "incipient bud primordial." They concluded that inositol was "inhibitory to the induction of bud premordial" and vitamins were not necessary for "bud and primordial induction."

In vitro culture of mature ponderosa pine has recently been initiated (Lin et al. unpublished). Axillary buds were induced from embryonic shoots without meristem tissue of mature ponderosa pine by initially using 1.0 mg/l 2,4-D + 0.5 mg/l BAP in MS media and 2 weeks later they were transferred into MS media with 1.0 mg/l BAP + 0.5 mg/l NAA. They found that different positions of explants on the trees significantly affected the formation of axillary buds. The explants located at the top of the trees formed more axillary buds than those from the lower crown of the trees. The season was also a critical factor for the axillary bud formation. The explants collected in winter never formed axillary buds but instead formed callus; whereas the explants collected in Autumn formed axillary buds, although small amount of explants produced callus. In another experiment, abundant callus tissue was obtained from needle explants of mature ponderosa pine by applying 1.0 mg/l 2,4-D + 0.5 mg/l BAP. By subsequently applying two subcultures of the callus tissue, tracheid mass with surrounding meristem tissue (vascular nodule) was observed from the callus after the second subculture. This indicated that callus derived from explants of mature ponderosa pines are capable of forming new tissue or organs. Gresshoff (1978) argued that the further development of vascular nodules in callus would lead to form "general premordium" and eventually to form buds or roots. In addition, from the callus culture, embryogenic callus capable of forming somatic embryos during their further development was found after two weeks growing on the first subculture Murashige-Skoog (MS) media (Murashige and Skoog 1962) with 1.0 mg/l BAP + 0.5 mg/l NAA.

KNOWLEDGE GAPS IN IN VITRO CULTURE OF PONDEROSA PINE

It is encouraging to see that ponderosa pine tissue culture has achieved considerable success in a short period of time. However, in vitro culture of ponderosa pine has limitations and much less effort has been devoted to its study compared with other gymnosperm species. Previously, much less work has been done on some aspects which play an essential role in in vitro culture of plants. The limitations of in vitro culture of ponderosa pine could be categorized in the following aspects: 1) Basal nutrient media selection, 2) growth regulator effects and 3) development procedures of explants in the culture media. Without a better understanding of these aspects, the process of in vitro culture of ponderosa pine will be inhibited.

Basal Nutrient Media Selection

Media, containing various minerals, amino acids, vitamins, and carbon sources, is a basic

nutrient source for explant growth. Different plant species, different organs, tissues, and different physiological ages require different nutrient compositions and concentrations (Teasdale 1987). Therefore, determining the correct media formula for different target plant materials is very important. Several standard media formula have been developed in some angiosperm species. MS media was originated for tobacco tissue. Lepoivre (LP) media (Quoirin and Lepoivre 1977) was developed for *Prunus*. GD media was developed for tomato tissue culture. Now, modified GD and LP medium have been widely used in gymnosperm species (Lesney et al., 1988, Aitken-Christie et al., 1988, Thorpe 1988, Arnold and Hakman 1988). Ball (1987) reported that MS media, as a universal media, was less effective than Wolter-Skoog (WS) media (Wolter-Skoog 1966) for in vitro culture of *Sequoia*. In the previous work of ponderosa pine, modified GD was found to be the best media for shoot formation of cotyledons and SH media initiated callus formation from cotyledons (Tuskan et al., unpublished). Ellis and Bilderback (1989) used half strength of SH media to induce adventitious buds from cotyledons which were not separated from embryos. It is not surprising to find that the adventitious buds could be regenerated from the cotyledons of ponderosa pine by using different treatments by Ellis and Bilderback (1989 and Tuskan et al. unpublished). However, the mechanisms are not known.

For evaluating media formula, several aspects should be well understood: 1) metabolic requirements of micronutrients in target tissue in vitro and 2) interactions among different compounds in media.

Metabolic Requirements of Micronutrient of Target Tissue In Vitro

Different physiological states of tissues would require different levels of the same compounds. Mature foliage of pine needs a lower amount of copper (Cu) than juvenile foliage, and the requirement of manganese (Mn) is the reverse (Teasdale 1987). *Pinus radiata* seedlings require 64 uM iron (Fe), whereas Douglas fir (*Pseudotsuga menziesii* [Mirb] Franco) embryo needs 27 uM Fe (Teasdale 1987). Bilderback and Ellis (1985) reported that inositol inhibited bud primordia induction of ponderosa pine embryo explants. The role of inositol on the other explants of ponderosa pine is not known.

Interactions of Compounds

Phosphate and iron in a media usually precipitate (Teasdale 1987). In MS media, it is reported that "over half the Fe is in fact precipitated by phosphate" (cited in Teasdale 1987). This indicated that the "metabolic interaction effects can dramatically affect the availabilities of some micronutrients" (Teasdale 1987). Therefore, when modifying standard media, this factor should be considered.

After the above knowledge is obtained, it would be easier to evaluate media. It is suggested to determine proper media for explant growth, micronutrient compound thresholds of deficiency and toxicity in target tissue needs to be measured. The concentrations of specific compounds in the media has to fall between the thresholds. Detailed methods of how to determine the media formula is clearly discussed by Teasdale (1987).

Determining the Appropriate Combination of Growth Regulators

Growth regulators play a very important and complicated role in plant tissue culture. They affect explant growth in the following ways: 1) Auxin alone would induce callus or roots; 2) Auxin and cytokinin combination would cause callus, shoots or roots depending on different ratios of auxin to cytokinin; 3) cytokinin alone usually induces shoots (Minocha 1987). However, the responses of target materials to growth regulators are usually hard to predict. Minocha (1980) did not observe any shoot formation from callus derived from embryos of *Pinus strobus* L., although he tried more than 100 growth regulator combinations. The physiological response of target materials primarily depends on the types of explants and species. Some tissues or organs are exogeneous auxin or cytokinin independent and some are highly dependent to exogeneous growth regulators during their development. In addition, it also depends on interactions among growth regulators and interactions between growth regulators and chemical compounds (Pierik 1987b, Gresshoff 1978). For instance, Skoog (1971) found that exogenous cytokinin stimulated thiamin, auxin, and other cytokinin synthesis in tomato tissue culture. The conclusion that vitamins were not an absolute requirement for buds and primordia induction (Bilderback and Ellis 1985) may be due to the fact that BAP stimulated the vitamin synthesis in the cultured ponderosa pine embryos. Unfortunately, the basic questions of mechanisms have remained uninvestigated in in vitro culture of ponderosa pine.

Development Process of Cultured Explants

In the previous work with in vitro culture of ponderosa pine, study of the development process of cultured explants has been neglected. The study of development processes can provide us with very valuable data. It helps us to understand the correlations between morphogenesis, growth regulators, and micronutrient compounds which allows for the determination of suitable media formula and growth regulators (Gresshold 1978).

The initial process of morphogenesis usually cannot be seen without histological and histochemical techniques. By applying these methods, we will be able to trace the development of

callus tissue, and to determine if a treatment is correct. In our experiment, although we did not induce any shoots or roots from callus, we observed histogenesis by using histological methods (Lin et al., unpublished). This at least demonstrated that the callus derived from explants of mature trees have the ability to form new tissue, and one of the treatments was suitable for callus development providing us with a clue for further study in this aspect.

FUTURE PROSPECTS OF IN VITRO CULTURE OF PONDEROSA PINE AND ITS POTENTIAL APPLICATION IN TREE IMPROVEMENT PROGRAMS

Ponderosa pine is one of the most widely distributed species in the western United States. Its lumber production constituted one-third of the total lumber production in the inland western United States during 1986 (Van Hooser & Keegan 1988), and the timber is utilized in various ways by forest industries. The great demand for ponderosa pine results in harvest exceeding growth in some western states (Van Hooser & Keegan 1988). This harvest/growth imbalance might cause a shortage of ponderosa pine in the future (Van Hooser & Keegan 1988). To increase the production of ponderosa pine to meet the future demand, one major strategy would be to improve timber production by basic tree improvement methods.

As we mentioned previously, in vitro culture technology plays an ever-increasing role in tree improvement programs, especially for gymnosperm species. The main purpose of tree improvement programs is to obtain maximum genetic gain in a given time. In conventional ponderosa pine tree improvement programs, several major constraints exist: 1) long-time breeding cycle, 2) grafting incompatibility, and 3) rooting difficulty. Ponderosa pine usually reaches maturity at age 20-40. Because of their long juvenile phase, once an elite trait is found, the genetic gain in the next generation would not be obtained for at least 20 years. Some elite traits will not be expressed until tree reaches maturity. For instance, ponderosa pine resistant to some insects may be recognized only when the tree reaches maturity. In routine progeny tests, it may not be possible to detect the resistant trait of progeny for at least 20 years. Attempts at rooting cuttings from mature ponderosa pine, while successful, did not meet commercial expectations (Wagner unpublished). The best rooting frequency was 27% and the rooted cuttings tend to grow slowly (Wagner unpublished). By applying in vitro culture techniques, this problem hopefully would be resolved.

In vitro culture of ponderosa pine is in a very early stage. Much effort is required before this technique can be applied to tree improvement programs. To rapidly develop in vitro culture of ponderosa pine, research should focus on basic research into growth processes and methods of in vitro culture.

Basic Research

As we have discussed earlier, most attention has been given to how to manipulate growth regulator combinations. Some fundamental research such as determining media formula and the essential knowledge of growth regulator mechanism has not been investigated. The above limitation was not only found in in vitro culture of ponderosa pine, but also exits in most in vitro culture of gymnosperm species. The necessity and urgency of the above fundamental studies are apparent and has been brought up by many scientists (Minocha 1987, Teasdale 1987, Mehra-Palta and Thompson 1987). The fundamental research requires large scale scientific effort. It would involve biochemists, botanists, forest geneticists, and forest breeders. The history of in vitro culture tells us that fundamental work could take considerable time. For instance, potato tissue culture techniques required 30 years to be developed and now the techniques greatly benefit potato production (Slack 1988). *Sequoia sempervirens* tissue culture techniques required almost 30 years Boulay 1987), but the results of these studies eventually resulted in mass propagation, and production of disease-free plants for the horticulture industry (Gresshoff 1978).

Accomplishing In Vitro Culture and Exploring Potential Applications

To date, in vitro culture of ponderosa pine is limited to the methods of embryo culture (Ellis & Bilderback 1989, Tuskan, unpublished), callus culture (Lin et al. unpublished), and axillary bud culture (Lin et al. unpublished). The system of in vitro culture of ponderosa pine has not been well developed. By applying other methods, the progress of in vitro culture of ponderosa pine might be accelerated and some genetic gain could be achieved in a tree improvement program in a short period of time.

Embryo Culture

Embryo culture is defined as "the sterile isolation and growth of an immature or mature embryo in vitro, with the goal of obtaining a viable plant" (Pierik 1987c); it has been demonstrated as a "reliable technique" for in vitro culture in gymnosperm species. Boulay (1987) indicated that embryo culture would increase the multiplication rate to 10-40 times higher than the multiplication rate by rooted cuttings for conifer species. It would be beneficial in the following situations: 1) when seed germination is poor; 2) when control pollination does not yield enough seed to meet reforestation need; 3) when interspecific and intraspecific crosses results in hybrids that yield poorly; and 4) to test species breeding criteria, such as resistance to diseases or pests prior to progeny tests.

Axillary Bud Culture

This is a method to obtain axillary buds in in vitro and subsequently to develop the buds into shoots, and eventually to obtain whole plantlets. This method could be applied to mass propagation of both juvenile and mature trees. It has been successfully applied in the multiplication of *Sequoia* (Boulay 1987) and loblolly pine (*Pinus taeda* L.) (Amerson et al. 1988). The "real benefit" of in vitro culture is the ability to propagate from mature trees because frequently it is impossible to determine the genetic potential from embryos or seedlings, unless there are juvenile-mature correlations (Bonga 1987, Mehra-Palta and Thompson 1987). We have developed a technique to obtain axillary buds from embryonic shoots of mature ponderosa pine (Lin et al. unpublished). This provides us with excellent starting material, since the axillary bud is a stable genetic base and has much less risk of variation than callus tissue within a generation (Pierik 1987d). Further effort to develop these axillary buds into shoots is needed in order to obtain plantlets. The continuous development of this technique could become an important tool in the asexual propagation of mature ponderosa pine.

Callus Culture and Cell Suspension Culture

Callus culture is a method in which mass of unorganized tissue, callus, is induced. The callus is then transferred into new medium in order to regenerate into organs or somatic embryos (Pierik 1987a). Cell suspension culture is defined as "cell and cell aggregates dispersed and growing in moving liquid medium" (Street 1977). Callus is often used as starting material in cell suspension culture.

Callus culture combined with cell suspension culture has been considered as a great potential tool to achieve regeneration from somatic embryos. Durzan calculated that 100,000 acres could be reforested with the plants which would be regenerated by embryogenesis from 100 liters of culture in only 3 months (cited by Aboel-Nil 1987). Cell suspension culture have yielded promising results in gymnosperm species recently. Out of 13 recent literature citations on embryogenesis, nine of them were applied cell suspension culture method (Attree et al. 1987, Boulay et al. 1988, Durzan and Gupta 1987, Gupta and Durzan 1987, Kartha et al. 1988, Krogstrup et al. 1988, Hakman and Fowke 1987, Hakman et al. 1985, Hakman and Arnold 1988). In ponderosa pine callus culture, it is encouraging to find embryonic cells which would be able to develop into somatic embryos in our callus culture. If cell suspension culture were applied, somatic embryos could have been produced.

Callus culture may have great value in mature tree propagation, since most mature trees could easily produce callus. It is also becoming a very powerful tool for bioassay of genetic resistance to disease (Mott & Amerson 1984, Diner & Mott 1982). Mott and Amerson (1984) reported that the callus derived from embryos of *Pinus lambertiana* showed genetic resistance to blister rust hyphae. This method could be applied to investigating ponderosa pine genetic resistance to insects. Since we have developed a method to obtain callus from needles of mature ponderosa pine, it may be possible to conduct a tissue culture bioassay of candidate resistance material. Callus culture can also be beneficial in gene pool conservation and the study of host-parasite interaction. One of the major tasks of tree improvement programs is to conserve germplasm for long term breeding programs (Zobel and Talbert 1984). In routine gene conservation of trees, large space is needed. By using in vitro culture technique, the germplasm could be stored in a limited space. This could be achieved by freezing tissues and callus. Zobel and Talbert (1984) predicted that in vitro culture will have great potential for gene conservation.

Protoplast Culture

This is a method in which cell walls are removed from the plant cells to "produce isolated protoplasts" (Evans & Cocking 1977). This method allows for somatic hybridization, in which two different protoplasts from different parents fuse combining genomes of the parents. This technique has great value for tree breeders. It can overcome genetic barriers in the crossing process. For example, an attempt to hybridize ponderosa pine (Cali.) with *P. tenuifolia*, *P. pringlei*, and *P. lawsonii* has remained unsuccessful (Conkle and Critchfield 1988). By applying protoplast culture, these crosses would become possible. Another advantage of somatic hybrids is that they can completely inherit genomes from both parents. In routine sexual production, progeny or hybrids usually do not completely inherit the genome from father. This is because during the process of fertilization, "hereditary characteristics localized in the cytoplasm are usually only inherited from the mother." (Pierik 1987e).

CONCLUSION

In vitro culture techniques are becoming powerful tools in mass propagation and tree improvement programs of gymnosperm species. Among gymnosperm species, in vitro culture of ponderosa pine has made considerable progress in a relatively short period of time. However, it is still in an experimental stage. With a future effort in fundamental growth process research and development of in vitro culture procedure for ponderosa pine, in vitro culture technology can make a great contribution to tree improvement programs for ponderosa pine. This technology can assist by reducing breeding cycles, providing for rapid genetic bioassays, gene conservation, and somatic hybridization to create unique genotype for future forests.

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Forest Diseases, Environmental Pollutants, and Other Stresses: Moderator's Comments

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In this session, there were five presentations describing how to model diseases, pollutants, and stresses. There was one presentation on site index evaluation and one presentation giving an overview on diseases that alter the growth and yield of ponderosa pine.

Jeffrey Miller described a methodology where relative impacts of air pollutants on different species can be put into a model. This model can then be evaluated over differing time horizons and relative impacts noted. This technique has been used in the San Bernardino Mountains to evaluate ozone. Some parts of the system are still under development. Use of this technique allows for evaluation of pollution impacts when time constraints permit in-depth model development.

The second presentation, by Marcel Rejmanek, described methods for estimation of woody weed competition on a ponderosa pine plantation. Field measurement techniques were described. Permanent plots were established and plot maps created. Competition impact on conifer growth, as was reported in this presentation, is important where multi-resource objectives call for the retention of non-conifer vegetation on a site.

The last modeling presentation was by Terry Droessler. Use of an empirical growth model to reflect tree growth changes can present some questionable conclusions. In this presentation, a case is made for assuring the basic growth model function to mathematically portray the desired impact.

William Stansfield presented a brief synopsis of site quality measures. In multi-resource management, disciplines other than timber management may reference site productive capacity differently. This presentation describes the different methods (site index, soil/site relationships, and habitat type) and shows how these methods relate to currently recommended site index techniques.

The last presentation of the morning session was a review presented by Borys Tkacz of diseases impacting ponderosa pine. Dwarf mistletoe and root diseases were discussed in detail. Trends toward management prescriptions which emphasize multistory, unevenaged, and multispecies forests can increase these forest pests. This presentation generated numerous questions from the workshop participants.

AIRSILVA: A Model of Mixed Conifer Forest Response to Multiple Stress[1]

Jeffrey Miller[2] and Lew Ladd[3]

Abstract. AIRSILVA is a model of mixed conifer forest community dynamics incorporating the population modeling capability of gap models and the mechanistic ecophysiology of process models to create a model where processes occur within individuals, and the failure of individuals to successfully complete processes results in population level dynamics.

The purpose of AIRSILVA is to synthesize the best available knowledge on the effects of air pollutants on the mixed conifer forests of southern California, and to project potential ecosystem responses under alternative pollution scenarios.

INTRODUCTION

Trees are notable for their long life-spans and large areas over which species or community types can be distributed. The scale of these organisms makes computer simulation modelling an important method for gaining insights into long-term community level responses of forests to multiple stresses. The stresses individual trees must deal with can be both natural, such as water or nutrient stress or man-caused such as ozone and acid-rain. But with the projected impacts of elevated CO_2, such as increased temperatures and corresponding water stress, these will be hard to separate.

Ecosystem functioning can be described at many levels of resolution. At each level of resolution there are certain appropriate phenomena of interest depending on the rates of the processes involved (O'Neill et al., 1986). Four time scales based on the cycles of nature are the diurnal (within a day), the seasonal (within a year), successional (within the disturbance frequency but without genetic change), and evolutionary (with genetic change). At the successional level the responses of forests to stresses usually focuses on species composition through time. Population models, such as gap models (Shugart, 1984) or vital attribute models (Noble and Slatyer, 1980) have been used to project the impacts of various stresses on the course of succession for many ecosystems around the world. Another view of succession concentrates on the changes in the rates and magnitudes of the processes which control the functioning of the ecosystem. Understanding these processes does not depend on knowing which individual within a species or within functionally similar species actually performs the functions.

AIRSILVA is a combination of the population modeling capability of gap models, and the

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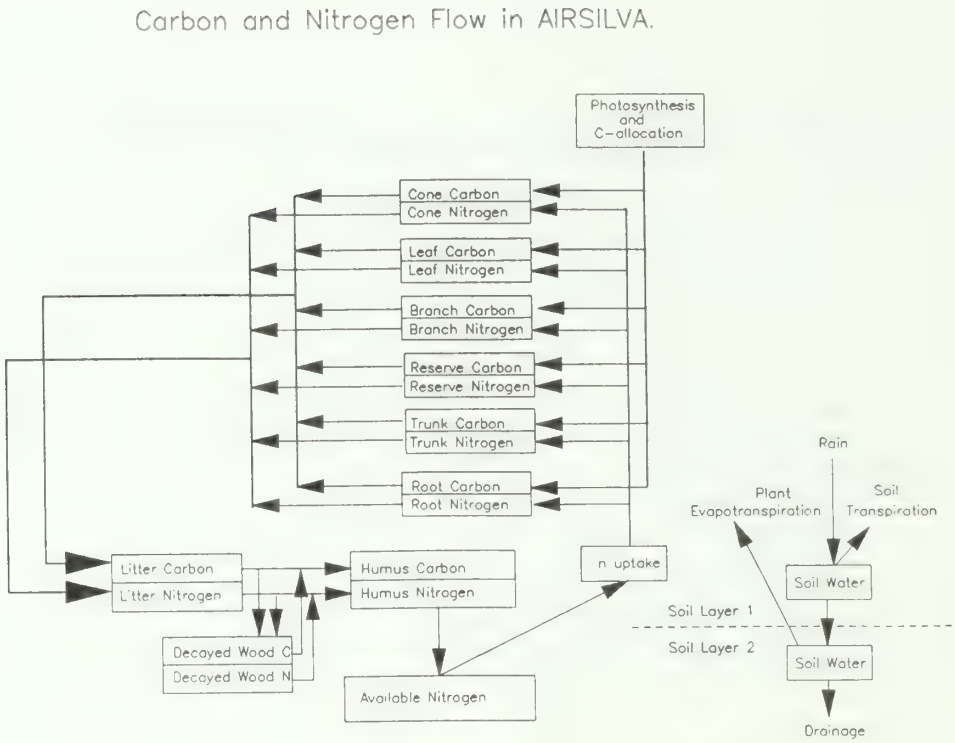

Figure 1. Each tree in AIRSILVA has 5 carbon compartments; leaves of up to 5 age classes, branches, trunk, roots, and cones. There are 4 corresponding nitrogen compartments; leaves of up to 5 age classes, wood (incorporating both branches and the trunk), roots and cones. Carbon acquisition of each tree is a function of environmental conditions and the leaf area. Carbon allocation is based on the trees desire to maintain an optimal carbon gain to nitrogen uptake ratio. Nitrogen uptake depends on the availability of nitrogen and the rooting volume. Nitrogen allocation at the community level is based on the relative demands of each individual tree and the decomposers. Nitrogen allocation within each tree depends on the relative sink strengths of each plant part. As litter ages it releases carbon and immobilizes nitrogen until it reaches a critical C/N ratio when it becomes humus and starts to release nitrogen as it continues to decompose.

mechanistic explanatory capability of process models. AIRSILVA is based on the gap model SILVA (Kercher and Axelrod, 1984a; 1984b) which is a version of the JABOWA model (Botkin et al., 1972) modified to simulate the mixed conifer forests of California and the roles of fire and SO_2 have on community composition. The modifications to SILVA replace the logistic growth function and rule-based growth constraining relationships found in most gap models with a simplistic set of ecophysiological functions that allow the effects of air pollutants to be incorporated with a degree of mechanistic realism.

The reason for emphasizing the mechanisms of plant growth is that air pollutant stress is not an external phenomena but is part of the system and causes the plant to emphasize different growth strategies. By modifying the patterns of allocation, as in increasing leaf area when the photosynthetic efficiency decreases, a plant may be able to compensate and forest succession over long time periods, thus retaining the capabilities of a gap model, and also explain the observed patters as the result of the underlying controlling processes. AIRSILVA is envisaged to be the longest time-scale model of a set

of three hierarchical models. The other two models concentrate on the diurnal physiologically responses of a forest canopy to pollutants, and the seasonal ecophysiological response of a whole tress. The purpose of these models is to synthesize the available understanding concerning the effects of air pollutants, specifically ozone and acid-rain, on ponderosa pine and the mixed conifer forests of the southern Sierra Nevada and San Bernardino Mountains as a contribution of the Western Conifers Research Cooperative to the National Acid Precipitation Assessment Program.

ASSUMPTIONS OF THE MODEL

AIRSILVA follows other gap models and simulates the growth of individual trees on a plot (Shugart, 1984). The size of the plot is determined by the requirements of a single individual of the species requiring the largest amount of space. When this large individual dies it creates a gap in the forest canopy. This opening is usually invaded by many individuals of a fast growing light-requiring species. As these individuals grow they shade one another and eliminate the shorter individuals. A second growth pattern consists of species which may be slower growing, but are tolerant of shade. The shade tolerant species can grow under a closed canopy of the light requiring species, and once the light requiring species die come to dominate the stand. This successional cycle can then repeat once the shade tolerant species dies, creating another gap.

Gap models have the ability to mimic the hypothesized pattern of forest succession, but do not explain succession as a function of underlying processes. Birth and death are simulated as random events which can be biased with rules relating to the environmental conditions. Each run of a gap model is a single possible sequence of random events, and the models are usually run many times to develop a central response tendency of a forest.

In AIRSILVA the rules found in other gap models that directly link the environment to growth have been replaced with rules relating the environment to physiological functions. This allows population level responses to be explained as a result of the underlying physiological processes. This also allows the plant to have the ability to compensate for the environment. The effects of air pollutants may be so subtle that they only show up in the plants compensatory processes rather than its overall response.

Unlike other gap models where a continuous supply of seeds of all species is assumed, the soil seed banks in AIRSILVA depend upon the reproductive efforts of the individuals on the plot. This follows the logic of the vital attributes model which emphasizes the idea that species composition after a disturbance depends upon the species ability to survive the disturbance as either a resistance adult or as a seed.

Each individual tree is described by a set of carbon and nitrogen contents in various plant parts (Figure 1). Within the plot there is no explicit spatial arrangement of the individual trees. The leaf area of each tree is distributed vertically into layers, and is assumed that the leaves in each layer are spread over the whole plot. The roots of each individual occupy a fraction of the total soil volume. It is assumed that these roots are evenly mixed throughout the complete soil volume. This effectively means that within a plot the trees are growing under or above each other, but not beside one another.

The model increments tree growth once a year based on photosynthate accumulated on monthly time steps. The monthly time step is used to incorporate both the fluctuations in total annual rainfall and the seasonal pattern of rainfall which determines the length of the summer drought. Monthly carbon acquisition is calculated with an instantaneous gas exchange model driven by the average environmental conditions during the month. Acquired carbon and nitrogen are placed into reserve compartments, and the annual allocation pattern is a function of the reserve nitrogen to carbon ratio. A lack of nitrogen will increase allocation to roots and a lack of carbon will increase allocation to leaves. Plant parts are assumed to maintain constant C/N ratios, so the total growth of all of the plant parts depends on the smaller of the two reserve pools.

Ozone is incorporated in the model as it is assumed to effect photosynthetic efficiency (Tingey and Taylor, 1982). Although acid rain has not be isolated as a major impact on western forests, AIRSILVA includes its possible effects on site nutritional balance first as a supply of nitrogen and then as a detrimental soil acidifier as deposition rates increase.

AIRSILVA is written in C for portability between personal computers, work stations, and main frames. In C the FORTRAN or BASIC subroutines are called functions. One of the strengths of object oriented computer languages such as C is the ability to organize related information into data structures which are addressable with a single variable name. AIRSILVA has two main data structures, the "tree"

Table 1. Information on each tree on the site is organized into a data structure called "tree". Of the thirty variable describing each tree the 12 parameters describe various properties of the tree, the 13 state variables describe the masses of carbon and nitrogen that comprise the tree and the accumulated ozone dose of each age class of leaves, and the 5 rate variables describe the transfer rates of carbon and nitrogen. Other information concerning each tree which does not need to be transferred between functions, such as the transpiration rate which is only used in the hydrology function, is not part of the "tree" structure.

Parameters:	tree number
	species code
	age
	annual growth ring width
	basal diameter
	height
	maximum branch mass attained
	crown thickness
	maximum crown thickness attained
	leaf area above canopy midpoint
	soil volume for water uptake
	soil volume for nitrogen uptake
State variables:	leaf mass (of up to 5 age classes)
	accumulated ozone dose (by leaf age class)
	carbon reserve mass
	branch mass
	trunk mass
	root mass
	new root mass
	cone mass
	leaf nitrogen content (by leaf age class)
	reserve nitrogen content
	wood (branch and trunk) nitrogen content
	root nitrogen content
	cone nitrogen content
Rate variables:	monthly average leaf conductance
	annual nitrogen uptake
	monthly net photosynthate (by leaf age class)
	annual wood respiration rate
	annual root respiration rate

and the "litter". Information on both the carbon and nitrogen masses of the parts of a tree, the exchange rates of these plant parts, as well as some general characteristics of the tree such as its height are arraigned in a linked list of objects called "tree". Similarly, each years litter production is separated by material type and placed in a linked list containing information on its carbon and nitrogen mass, age, material type, etc. By using a linked list structure instead of an array, information does not have to be moved around in the computers memory; only a pointer to the location of the information needs to be updated. This data structure has greatly enhanced the computational speed of AIRSILVA and allowed model development to proceed on personal computers.

The data structure "tree" describing each tree consists of 30 variables (Table 1). Twelve parameters describe which tree the individual is (tree_number), its species, age, annual ring width, basal diameter, height, the volume of soil available for exploitation of water and nitrogen, and three values used to determine the base of the crown. Thirteen state

```
main()
        {
        init_stand()
        for (year = 0 to number of years in run)
                {
                init_output()
                climate()
                birth()
                        add_trees()
                community()
                        get_leaf_area()
                for (month = 0 to 12)
                        {
                        hydrology()
                        c_up()
                        }
                decomp()
                        newcohort()
                n_up()
                grow()
                        carbon_alloc()
                fire_()
                kill()
                yearly_output()
                }
        }
```

Figure 2. AIRSILVA consists of 13 primary functions and has a one year time-step except for the hydrology and c_up functions which have monthly time-steps. The initial stand conditions are defined in init_stand(). Within the yearly loop climate for the year is generated in climate(), new trees emerge in birth(), and community() defines some general conditions on the plot. The plot water balance is calculated once a month in hydrology(), and the effect this has on carbon uptake is calculated in c_up(). Once a year decomp() determines the breakdown of organic matter and nitrogen availability for uptake in n_up(). The function grow() determines the growth of each tree on the plot based on the acquired carbon and nitrogen. Fires may occur and kill individuals in the fire_() functions, and then kill() removes trees that have died either due to an inadequate carbon gain for the year or as the result of fire. Finally the yearly_output() summarizes values on the water balance of the plot, the carbon and nitrogen cycling, and the population dynamics of each of the species on the plot.

variables describe the carbon and nitrogen biomass compartments; leaf carbon and nitrogen (of up to five age classes), reserve carbon and nitrogen, branch carbon, trunk carbon, wood (both branch and trunk) nitrogen, root carbon and nitrogen, cone carbon and nitrogen, the new root carbon mass, and the accumulated ozone dose. Five rate variables; the leaf conductance, the net photosynthesis rate, the nitrogen uptake rate, and the wood and root respiration rates are also part of the tree structure since they are used in several functions and need to be related to a particular tree. All of the masses maintained in the model are in kilograms, and the distances are in meters.

The model is built in modules (C functions) that exchange information. Each function can be modified and improved or treated as a black box as needs vary, as long as the function performs the minimal tasks required of it by other parts of the model. Because

the model includes numerous stochastic components it can be run several times and average responses determined, or the results of a single run can be analyzed.

AIRSILVA consists of 13 primary functions; init_stand, init_output, climate, birth, community, hydrology, c_up, decomp, n_up, grow, fire_, kill, and yearly_output (Figure 2). The function init_stand is called once at the beginning of each run to initialize the stand, and the other functions are then called once each year except for hydrology, and c_up which are called once a month.

Stand initialization

The init_stand function defines the initial conditions of the stand at the beginning of each run. The model starts with "post fire" conditions; there are no trees, and no above ground accumulated litter. There is root litter, soil organic matter (humus), and corresponding nitrogen contents, and an initial seed bank of each of the species. The init_stand function also calculates the total water storage capacity of the plot, which depends on the water holding capacity of the soil (l/m^3), the plot size and soil depth, and the rock content of the soil. The model starts with saturated soil water conditions.

The variables that summarize the conditions on the plot at the end of each year are initialized in the init_output function. The output variables summarize four general areas; plot water balance, nitrogen cycling, carbon cycling, and population dynamics.

Climate

The climate function corrects the monthly mean temperatures at the nearest weather station for the adiabatic lapse rate due to the elevation difference between the weather station and the plot being simulated. The number of degree-days over 5°C are summed, and the monthly potential total solar radiation is corrected for losses from clouds. The monthly mean and standard deviations for precipitation, ozone concentration, H+, N, and S deposition are supplied to the model as required data. For each month of the year the climate function generates values for these parameters from normal distributions.

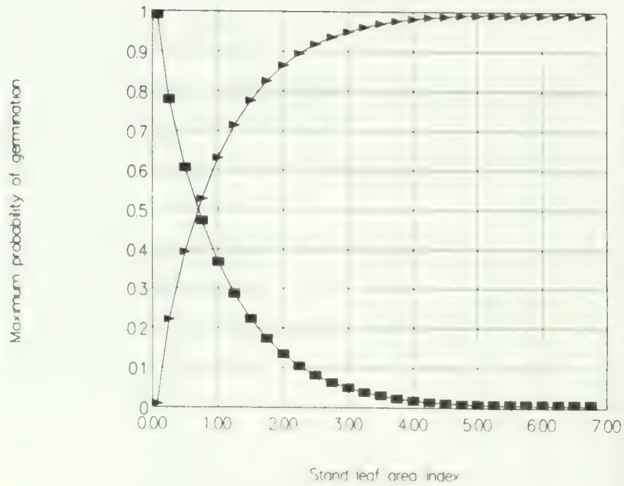

Figure 3. If the accumulated degree days at a site are within the species specific minimum and maximum tolerable then germination success depends on the species sensitivity to shade. Species are either shade requiring (▸) or shade intolerant (■). The annual germination rate (seedlings/m^2) is a uniform random number up to the potential maximum described by the light response function.

Birth

The birth and the add_trees function that birth calls add new individuals to the stand. If the annual degree day total is between the species specific minimum and maximum required for germination a fraction of the seeds in the soil germinate. The number of seeds that germinate is determined stochastically, with shade requiring and shade intolerant species having two different probability patterns as a function of the stand leaf area index (Figure 3). With increasing leaf area the shade intolerant trees have a decreasing probability of germination, and the shade requiring trees have an increasing probability of germination.

New seeds are added to the soil seed bank based on the reproductive efforts of the trees on the plot, and from off of the plot. This latter source prevents local extinctions of a species (as represented by either an adult or a seed) on the plot. Once the birth function has calculated the number of new individuals of each species to be added to the plot, the initial masses of the seedlings and the other parameters maintained for each individual are defined in function add_trees. Seeds loose viability and die following values reported for the model SILVA (Kercher and Axelrod, 1981).

Community totals

The community function sorts the linked list of trees by height so the leaf area index above each individual can be calculated in the function get_leaf_area. The leaf canopy of the community is divided into 25 layers from the top of the tallest tree to the ground. The leaf area in each layer is assumed to cover the whole plot. The leaf area of each individual is distributed vertically along its trunk from the crown base to the top of the tree following a normal distribution. The leaf area each individual contributes to the community canopy profile is summed. The leaf area above an individual consists of the leaf area in the canopy layers above the midpoint of the individuals canopy, and half of the leaf area of the layer at the midpoint. The light level at the midpoint of each individuals canopy is calculated following Beer's law (exponential decline). It is assumed that the leaves of each age class are equally distributed vertically, so all leaf classes experience the same light levels.

The community function also determines the volume of soil that the roots of each tree can potentially exploit for water and nitrogen. The potential maximum volume of soil that the roots of the community can exploit for water is the sum of the volumes of each individual. These cylindrical volumes are calculated from the root mass of the individual converted to a length, and a radius around the root. Water uptake is assumed to occur along the complete root length. When the potential exploitable volume of the community exceeds the actual soil volume, each individual then exploits a fraction of the total soil volume equal to its volume divided by the community volume. Nitrogen uptake follows a two dimensional version of the same algorithm since it is assumed that the nitrogen dynamics take place at the surface of the soil. The nitrogen exploitable area is the rectangular area described by the root length and the exploitable distance from the root. As with the distribution of leaf area there is no spatial component in the distribution of each individuals roots in the community. All of the roots can explore the complete soil volume of the plot. The roots are also not distributed vertically, but it may be more appropriate to distinguish two rooting zones, and have the trees either allocate to growth of surface roots for nitrogen uptake, or deeper roots for water uptake.

When the soil volume that could be exploited by the whole community is less than the total soil volume, the rate of nitrogen and water return to an individual limited by the carbon investment into roots. When the soil volume that could be exploited by the whole community is greater than the actual soil volume, the rate of return to an individual depends on its investment relative to all the other individuals. Since less than optimal C/N ratios within a tree will cause more investment into roots, this process of return related to investment simulates the individuals competing for nitrogen and water.

Plot hydrology

The plot water balance is calculated in the hydrology function and the satvap and penmon functions which hydrology calls. During the one year time step of AIRSILVA the hydrology function is called once a month in order to capture both the variations in total annual rainfall, and the seasonal pattern of rainfall as it influences the summer drought.

On a monthly time step the random amount of rainfall generated in the climate function is added to the top soil layer. If this new soil water content is greater than the water holding capacity of the layer then the excess is transferred to the second soil layer. If the second soil layer then contains more water than its holding capacity the excess is lost to drainage. The soil water contents of the two soil layers determine the soil water potentials of the two layers following a generalized soil water content to soil water potential function (Jeffrey, 1987). The water potential of the upper layer determines the soil surface conductance (Figure 4) which is then used in the Penman-Monteith equation (Monteith, 1973) to calculate actual soil evaporation.

It is assumed that the plants only extract water from the lower soil layer. The potential maximum water uptake is determined by the volume of soil exploited by the roots and the soil water content. The monthly average leaf conductances to water loss are based on the soil water potential, the monthly average light level, and the vapor pressure deficits following Jarvis (1976) as modified by Landsberg (1986). Actual transpiration is then calculated by the Penman-Monteith equation, but can not exceed the potential maximum uptake. After soil evaporation has removed water from the upper soil layer, and the trees have removed water from the lower soil layer, there is vertical water movement based on a soil hydraulic conductivity value determined from the average of the water potentials of the two soil layers.

The soil is assumed to have a capacity to buffer $H+$ deposition. If the accumulated deposition occurs faster than the soils ability to regenerate this buffering capacity the system will cross a threshold and nitrogen

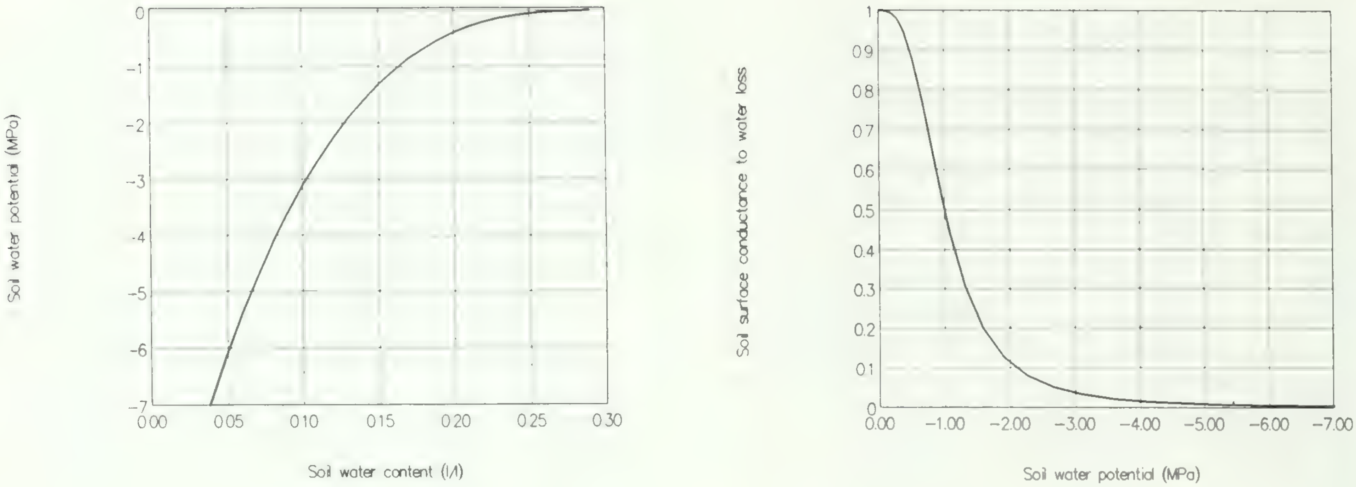

Figure 4. Soil water potential is calculated from a general relationship between soil water potential and soil water content (Jeffrey, 1987). The soil surface conductance to water loss is calculated from soil water potential based on a general function from Landsberg (1986). Both functions can be easily parameterized to fit soils of a specific site.

will begin to be leached from the soil. The rate of leaching is proportion to the available nitrogen and how far the soil buffering capacity has been pushed beyond the threshold.

Carbon acquisition

Along with the hydrology function carbon acquisition and respiration costs are calculated in function c_up once a month within the basic yearly time-step of the model. The average rate of photosynthesis for the month is calculated following Landsberg (1986) from the average leaf conductance determined in the hydrology function, temperature, photosynthetically active radiation, external CO_2 concentration, and the species specific potential maximum rate. This instantaneous rate is then multiplied by the day length and the number of days in the month. The photosyntheses equation incorporates leaf respiration, and the resulting net photosynthesis is calculated for each of the leaf age classes present on the tree. Leaf, wood, and root respiration rates depend on a base rate and a Q_{10} temperature function.

As leaves age the maximum photosynthetic rate decreases (Coyne and Bingham, 1982). Based on the field measurements of Coyne and Bingham (1981) the maximum rate of photosynthesis is assumed to decrease linearly with accumulated ozone dose. The ozone dose depends on the external concentrations and the leaf conductance. The maximum rate of photosynthesis also decreases linearly when leaf nitrogen contents are less than an assumed optimum. The production of photosynthate is assumed to require nitrogen. The carbon gain of all of the trees increases the plant nitrogen demand used in the decomposition function to allocate nitrogen between the trees and the decomposition processes.

Decomposition

The decomp function follows the decomposition routine developed by Pastor and Post (1985) in the gap model LINKAGES. Litter generated in the function grow is of one of five materials; root, leaf, twig, small wood, or big wood. Each year a cohort of each class of material may be generated (as described in function grow). Each of these cohorts is then place in the linked list of cohorts and begins the decomposition process.

Each cohort of litter has a carbon and nitrogen content. Each year the material decomposes and releases carbon and immobilizes nitrogen until the material has reached a critical C/N ratio. These threshold C/N ratios vary depending on the type of material, and determine when the material is either transferred to the humus pool or the decayed wood pool in the case of the two classes of wood. Decayed

wood continues to release carbon and immobilize nitrogen, but at a faster rate than the two types of wood litter. The humus also releases carbon, but in doing so releases nitrogen for either uptake by the plants or the decomposition process.

Because the decomposition of each cohort of litter and each tree is competing for the available nitrogen a total demand is calculated based on how much nitrogen all of the trees need to satisfy their growth, and how much nitrogen each decomposing litter cohort could immobilize as it releases carbon. If this total demand is less than the available nitrogen then each cohort releases its complete amount of carbon, and immobilizes its complete amount of nitrogen. If the total demand is greater than the available nitrogen then the fraction of the available nitrogen each cohort can immobilize is proportional to its demand divided by the total demand. The amount of nitrogen immobilized then determines the amount of carbon released.

The potential rate of carbon release is presently a fixed fraction depending on litter material. The nitrogen that is immobilized in releasing this carbon depends on the litter material. Carbon release should be a function of evapotranspiration and litter lignin to nitrogen contents as in LINKAGES, if these regression equations can be developed for the litter in southern California. Following LINKAGES humus releases 3.5% of its carbon and nitrogen each year, and as with the litter decomposition this should be made a function of the soil moisture availability and humus quality. Atmospherically deposited nitrogen is assumed to join the available nitrogen pool, and there is a fixed soil weathering rate adding nitrogen to the soil.

Nitrogen uptake

Nitrogen uptake by each individual tree is calculated in the function n_up. The previous years growth in function grow defined a demand for nitrogen by all of the trees. This years carbon acquisition increased the total plant demand. The fraction of this total demand which can be satisfied was decided in the decomp function which divided the total available nitrogen between the trees as a group and the decomposition processes. Within function n_up each tree receives a fraction of the nitrogen available to the trees. The amount of nitrogen an individual can take up is based on either the absolute volume of soil exploited, or the relative volume of the individual as a fraction of the complete community as described earlier.

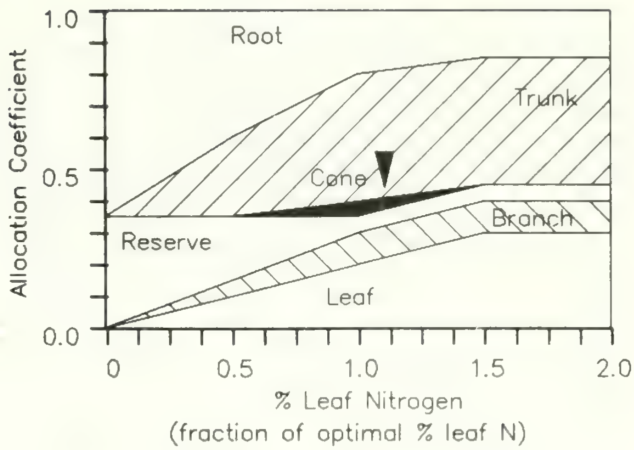

Figure 5. Allocation of carbon and nitrogen to the various plant parts depends on the ratio of reserve nitrogen to reserve carbon. The various plant parts have fixed nitrogen contents per unit carbon so the total amount of growth that can occur in a year is limited by the smaller of the two reserve supplies.

Growth and allocation

The function grow takes the nitrogen uptake values from the n_up function and the carbon acquisition and respiration values from the c_up function and calculates the net carbon available for growth. The function then calls the carbon_alloc function which determines the allocation patterns for both carbon and nitrogen, and increments the plant masses (i.e. growth). If any of the plant parts are to be shed the grow function also accumulates this years litter.

Each of the leaf age classes must be a net exporter of carbon otherwise the age class is declared dead. Premature leaf death occurs when photosynthesis has been inhibited by exposure to ozone. Re-translocation of nitrogen and carbon out of a leaf class dying prematurely is not as efficient as when leaves die naturally. Each species has a maximum leaf life span, and the leaf class exceeding this age is transferred to leaf litter. Some of the nitrogen and carbon is re-translocated to the reserve compartments. Re-translocation is not completely efficient and a fraction of the nitrogen in the leaves becomes leaf litter nitrogen and most of the leaf carbon becomes leaf litter. The one year time-step of the model make realistic fine root turn-over difficult

to simulate. In AIRSILVA half of the root mass is defined to turn-over each year. This allows the fine root mass to not be completely dependant on each years allocation to roots and allows the mass to increase as the tree grow. Root nitrogen is re-translocated from the roots and a fraction is transferred to root litter nitrogen. Some of the root carbon is also re-translocated to reserves, and the rest becomes root litter. Branch shedding occurs when there is more branch mass than is needed to support the leaf mass. Branch shedding removes nitrogen from the wood nitrogen pool in relation to the amount of branch mass shed. No carbon is assumed to be returned when branches are shed. After the wood and root respiration costs have been satisfied, the net photosynthate is added to the reserve compartment. If the carbon reserves of a tree become negative then the tree is dead.

The allocation pattern for assigning carbon and nitrogen to leaves, reserve, branches, trunk, reproduction, and roots is a function of the reserve nitrogen to reserve carbon ratio (Figure 5). If the plant is light limited then the carbon reserves will decrease in relation to the nitrogen reserves. With high N:C ratios allocation shifts from roots and branches to leaves and trunk. If the N:C ratio decreases due to nitrogen limitations then allocation is shifted from the leaves, branches, and trunk to the roots.

The various plant parts are assumed to have constant nitrogen to carbon ratios, which define how much nitrogen is required to balance the allocation of carbon. If the required nitrogen is less than the reserve nitrogen then allocation uses all of the reserve carbon and as much of the nitrogen as is needed. If there is not enough nitrogen to satisfy all of the carbon allocation then allocation proceeds to the limit of the nitrogen supply. The allocation of carbon and nitrogen from the reserves back to the reserves allows the plant to maintain a supply to live on when conditions are less favorable.

Growth respiration and the cost of converting photosynthate into plant parts accounts for a fraction of the material allocated to each plant part. The model does not presently account for secondary leaf thickening, or allow partial death of any leaf age class.

When the cone carbon pool reaches 10 kg there is a reproduction event and the pool is set to zero. This event translates to a potential maximum number of viable seeds, depending on the cone nitrogen content. Less than an optimum C/N ratios cause fewer viable seeds. The 10 kg threshold value needs to be adjusted so that there is an appropriate periodicity in reproduction determined by the length of time it takes for the plant to accumulate sufficient reserves.

The basal diameter and height of the tree are calculated by turning the trunk mass into a cone shaped volume which has a species specific height to diameter ratio. The crown of the tree is initially distributed from the top of the tree to the ground. When the first branch shedding occurs a crown depth is defined as the height of the tree at that point. The branch mass is also recorded as the maximum branch mass. As the tree continues to grow the crown becomes a fraction of the total height of the tree equal to the crown depth. If the branch mass falls below the maximum branch mass the crown depth decreases. This allows AIRSILVA to simulate the observed pattern of ozone killing the lower branches and decreasing the crown ratio of ponderosa pine (Miller and McBride, 1988).

Fire

The set of fire_ functions calculate a probability of fire ignition, and then fire propagation based on the fuel load. Fires require sufficient litter load to ignite, and once burning kill trees based on their height and sensitivity to fire. The model views the linked list of trees organized by height as a fire ladder, and flames can jump up this ladder killing individuals until there is a step in height too large to jump. The size of the step that stops the fire ladder depends on moisture conditions, with drier conditions allowing the fire to jump larger steps. Sensitive species which have thin barks are killed whether or not their canopy is burned as in the model SILVA (kercher and Axelrod, 1981).

Death

The function kill removes individuals from the linked list of trees that have been tagged as DEAD in the function grow or the function fire_. When individuals die the leaf carbon and nitrogen contents are transferred to leaf litter as is the plant reserve carbon and nitrogen. The branches on the tree and the cones are transferred to the twig litter class and their nitrogen contents are transferred to the twig litter nitrogen pool. The trunks of the tree are either transferred to big wood or small wood litter depending on whether the trunk basal diameter was greater than 0.1m. Root carbon contents and nitrogen contents are transferred to root litter.

Table 2. AIRSILVA generates output files concerning the annual hydrological balance of the plot, the nitrogen cycling, the carbon cycling, the number of individuals by 0.1 m increments in basal diameter of each species, and a file following one specific tree.

	AIRSILVA annual output values
Water balance:	total rainfall
	soil drainage
	potential soil evaporation
	actual soil evaporation
	potential plant evapotranspiration
	actual plant evapotranspiration
	average soil water content (2 soil layers)
	average soil water potential (2 soil layers)
Nitrogen cycling:	potential nitrogen immobilization by decomposition
	actual nitrogen immobilization by decomposition
	potential plant uptake
	actual plant uptake
	mineralized
	total available
	leached
	leaf litter nitrogen content
	twig litter nitrogen content
	large woody debris nitrogen content
	small woody debris nitrogen content
	root litter nitrogen content
	decayed wood nitrogen content
	humus nitrogen content
	leaf nitrogen content by species
	reserve nitrogen content by species
	wood nitrogen content by species
	root nitrogen content by species
	cone nitrogen content by species
Carbon cycling:	leaf litter mass
	twig litter mass
	large woody debris mass
	small woody debris mass
	root litter mass
	decayed wood mass
	humus mass
	leaf mass by species
	reserve mass by species
	wood mass by species
	root mass by species
	cone mass by species
Population dynamics:	number of individuals by 0.1m increments in basal diameter by species
	number of viable seeds per m^2 by species
Single tree:	leaf mass (of up to 5 age classes)
	reserve carbon content
	branch mass
	trunk mass
	root mass
	new root mass
	cone mass
	leaf nitrogen contents (by age class)
	reserve nitrogen content
	wood nitrogen content
	root nitrogen content
	cone nitrogen content
	annual growth ring width
	basal diameter
	height
	leaf area index above the canopy midpoint

Annual summaries

The yearly_output function generates output files on the nitrogen cycling, carbon cycling, plot hydrological balance, and the population dynamics of each species on the plot (Table 2). Individual trees can also be tracked in a fifth output file.

USES OF THE MODEL

AIRSILVA will be used to simulate three areas of ecosystem functioning; the hydrological balance, nitrogen cycling, and carbon cycling, and the effects these processes have on the species composition and size structure. The model will have the ability to investigate how these processes influence species succession, and how the shift in species composition influences the underlying ecosystem processes. AIRSILVA will be used to simulate the four broad areas; water balance, nitrogen cycling, carbon cycling, and population dynamics under natural conditions i.e. with "pre-man" fire frequency, with fire suppression, with the natural fire frequency and ozone, with the natural fire frequency and acid rain, and with actual conditions i.e. fire suppression, ozone, and acid rain. The ecosystem responses to various future patterns of air pollutant emissions will also be investigated as part of the National Acid Precipitation Assessment Program.

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Quantification and Prediction of Woody Weed Competition in Ponderosa Pine Plantations[1]

Marcel Rejmanek and John J. Messina[2]

Abstract.-- Developing methods for quantifying competition is essential for forest vegetation management. Angular neighborhood competition index was calculated using field data on shrub species. Regression analysis revealed that the growth rate of ponderosa pine was negatively and significantly dependent on this index. Path analysis indicated only negligible contribution of competition for soil moisture to the total competition influence of shrubs. Irrigation experiments supported this conclusion.

INTRODUCTION

A common assumption in mediterranean and sub-mediterranean climates is that the success of reforestation is dependent upon soil water availability which is negatively influenced by the amount of competing vegetation. Previous forest management practices to reduce stresses imposed on conifer seedlings by woody weeds have emphasized the use of herbicides, but an increasing public interest concerning health and ecological aspects of extensive forest herbicide use has stimulated research into other, alternative solutions. Some very basic questions remain unresolved: How to quantify and predict stressful conditions for conifer seedlings? When are herbicide applications necessary and when are tree yield losses comparable with the price of herbicides and/or other investments? What are the best estimates of economic thresholds? Answering these questions would certainly help reduce herbicide use in revegetation programs. Development of biologically sound, practical, and efficient methods for the study of woody weed - crop tree competition seems to be the first logical step in this effort.

Implementation of large-scale chemical brush control is based on many competition studies showing the importance of mean woody weed density and/or cover on growth and survival of crop trees (e.g., Stewart et al. 1984, Radosevich 1984, White 1986, Petersen et al. 1988). These approaches assume that average density or cover provide effective predictors of the state of the tree population without considering individual variation (Firbank & Watkinson 1987, Rejmánek et al. 1989). However, trees respond primarily to the proximity and behavior of neighboring plants and not to mean density or cover of woody weeds. By ignoring local interactions among individual plants, the real mechanisms of interference are obscured. Determining whether some or all of the neighbors are actual competitors, and what degree of stress each imposes on the focal plant, are unresolved problems.

This shortfall has warranted the development of spatially explicit and size-weighted expressions known as competition or neighborhood indices (Hegyi 1974, Lorimer 1983, Weiner 1984, Silander & Pacala 1985, Rejmanek & Messina 1989). We believe that a neighborhood approach, in which the attributes of neighbours (e.g., number, distance, spatial arrangement) are considered as they effect a focal plant, affords a number of advantages in examining woody weed - crop tree interference. Some of these competition indices represent promising candidates for competition functions in forest vegetation models, and their predictive value is being evaluated in both experimental and regular forest plantations using linear and nonlinear regression analysis. This analysis will be used later for estimation of economic thresholds. Because individual trees instead of means for individual experimental stands are used in the analyses, the neighborhood competition approach requires a much smaller total research area than methods mentioned earlier.

Our major goal is to evaluate indices of neighborhood interference in crop tree-woody weed situations with respect to (i) effective neighborhood radius, (ii) species differences, and (iii) soil moisture regime. Tree stem diameter, height, stomatal conductance, and net photosynthetic rate are used as indicators of stress and yield losses caused by woody weed competition. Results will be interpreted in terms of economic thresholds and management options (e.g., justification of the necessity and size of mulch collars around conifer seedlings in those areas where use of herbicides has been suspended by court action (Craig & McHenry 1988, Averill 1989, Smith 1989).

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[1]Paper presented at the conference on Multiresource Management of Ponderosa Pine Forests, Flagstaff, AZ, November 14-16, 1989.

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There have been very few silvicultural experiments in which water is the independent variable (Axelsson & Axelsson 1986, Brix 1972, Jarvis 1985, Kramer & Kozlowski 1979, Landsberg 1986, Newton et al 1986). These experiments ignored the role of weeds. In spite of the fact that competition for moisture between woody weeds and conifers is supposed to be the most important process determining success or failure of forest plantations in California and some other states (Radosevich 1984, Carter et al. 1984, Sands & Nabiar 1984, Shainsky & Radosevich 1986, White 1986, Petersen and Maxwell,1987), there are no experimentally generated data which quantify the influence of artificial augmentation of soil moisture on competition. In an ongoing irrigation experiment we are testing the hypothesis that yield losses of conifer seedlings caused by woody weed competition can be substantially reduced by soil moisture augmentation during critical periods.

STUDY SITE AND METHODS

We initiated several experiments on neighborhood competition in Blodgett Forest Research Station (BFRS, El Dorado, Cal.) during 1986-9. Detail analyses of neighborhood competition is being conducted in three fenced control (no treatment) mixed plantations in compartment 370 of BFRS. Maps indicating canopy cover, height, and position of seedlings of nine naturally occurring shrub species in 170 permanent plots of 2.5 m radius centered on two-year-old planted seedlings of either Pinus ponderosa (ponderosa pine), Sequoiadendron giganteum (giant sequoia) or Pseudotsuga menziesii (Douglas-fir), all planted in 1985, were drawn in 1986. Stem diameter at 5 cm and height of all three conifers were measured in Oct. 1986, Nov. 1987, and Nov. 1988. Major woody weed species studied are greenleaf manzanita (Arctostaphylos patula), mountain whitethorn (Ceanothus cordulatus), Sierra gooseberry (Ribes roezlii), and bush chinquapin (Castanopsis sempervirens).

Digitized data from these maps were stored by a special program written in BASIC and rechecked after ploting on Macintosh ImageWriter. Employing another original program, eight different indices of neighborhood competition were then calculated (Rejmánek & Messina 1989). Angular or "sum of angles" competition index (fig. 1) derived from Lin's (1974) "growing space index" proved to be a most promissing predictor of competition influences of woody weeds on ponderosa pine because the field data required are easily collected and the resulting predictions are not significantly different from predictions based on more sophisticated indices (Rejmánek & Messina 1989). Measurements of predawn leaf water potential and net photosynthesis rates expressed as a function of this index and other competition indices support this conclusion.

Predawn leaf water potential of conifer seedlings was measured using a Scholander pressure chamber (Scholander et al. 1965, Koide et al. 1989). Soil moisture was determined gravimetrically (Slavik 1974). Path analysis (Le Roy 1960, Kenny 1979) was used to suggest the most important direct and indirect cause-effect connections between the considered variables and the amount of variance accounted for by each.

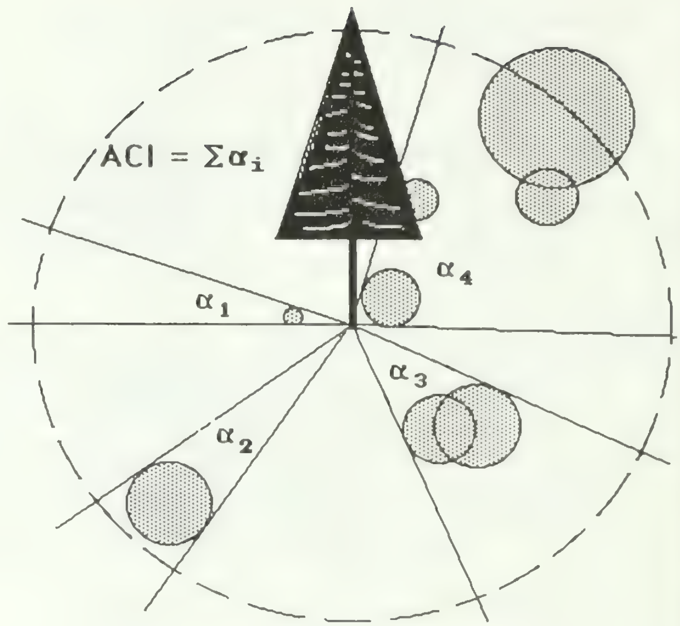

Figure 1.--Angular neighborhood competition index (ACI) is the sum of angles (α_i) formed by the two most distant edges of the individual plants or their aggregations and vertex corresponding to the position of a conifer seedling (the center of the picture). Individual competing plants (shrubs) are indicated as closed circles.

Eighty different permanent plots (BFRS, compartment 360) analyzed in 1987 were used for irrigation experiments in 1988 and 1989 to test the hypothesis that yield losses of ponderosa pine caused by woody weed competition can be substantially reduced by soil moisture augmentation during critical periods. A drip irrigation system was built to provide three experimental moisture regimes in 1988: control, low irrigation (once every 4 weeks, the amount corresponding to 80 liters per tree each irrigation) and high irrigation (once every 2 weeks). Only two moisture regimes were maintained during growing season 1989: control and irrigation (once every 2 weeks, the amount corresponding to 160 liters per tree each irrigation).

RESULTS AND DISCUSSION

With few exceptions, only the most abundant shrub species -- Arctostaphylos patula (greenleaf manzanita) -- contributed significantly to the regressions of relative diameter growth rate on angular competition index (fig.2). The most significant regressions were obtained for ponderosa pine when data from plots of 2.0 or 2.5 m radius were used (fig. 3). Preliminary analyses of the root system of ponderosa pine seedlings helped to explain this result: lateral roots of ponderosa pine were up to 220 cm long in 1987. Regressions of conifer seedling height growth rate on the angular competition index were less significant and are not shown here.

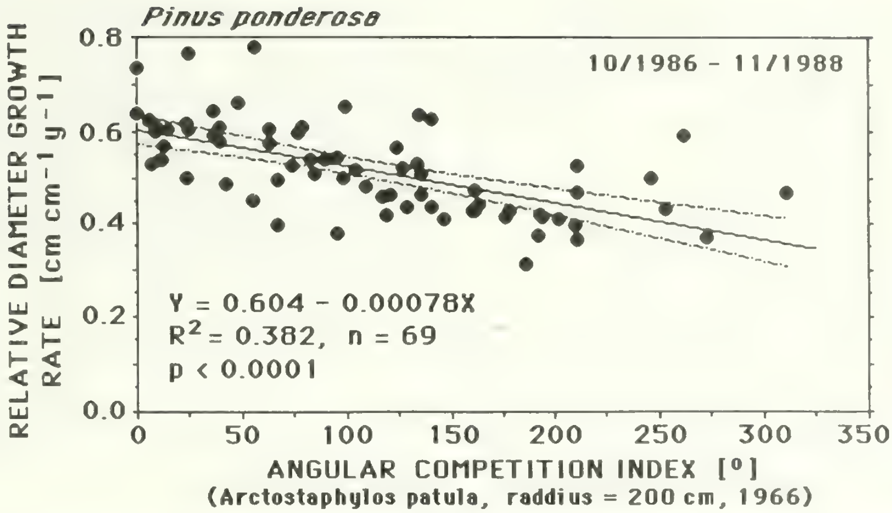

Figure 2.--Depedence of mean relative diameter growth rate of ponderosa pine over the period 10/1986 - 11/1988 on angular competition index (ACI) for greenleaf manzanita (Arctostaphylos patula) in plots of 200 cm radius analyzed in 1986. Dashed curves indicate 95% confidence bands for the true mean of Y.

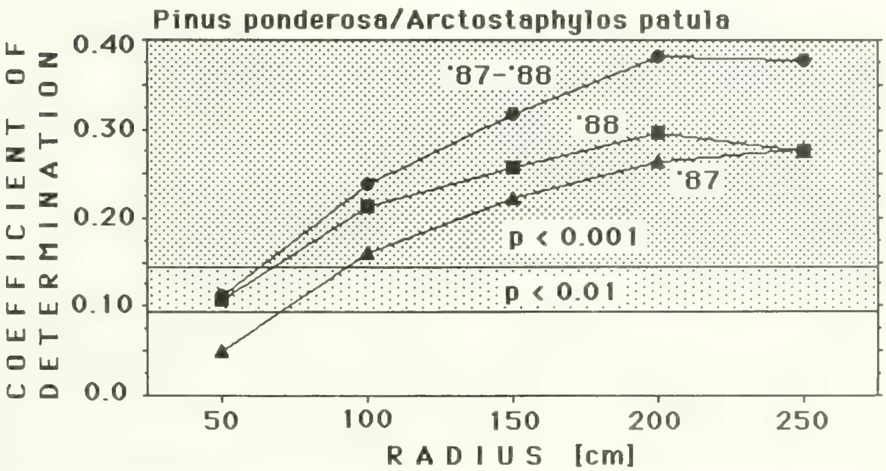

Figure 3.--Dependence of coefficient of determination (R^2), on the radius of sampled plots for the regressions of relative diameter growth rate of ponderosa pine on angular competition index (ACI) for greenleaf manzanita.

Not only growth of ponderosa pine seedlings was significantly negatively dependent on the angular competition index but soil moisture and predawn leaf water potential were significantly negatively dependent on this index as well (fig. 4). This dependence suggests that competition for soil water might be an important factor affecting the growth of ponderosa pine seedlings - a relationship hypothesized by many other authors. However, a simple path analysis (fig. 5) exploring the influence of soil moisture and predawn water potential indicated only negligible contribution of competition for soil moisture to the total competition influence of shrubs on ponderosa pine seedlings. Because most of the shrubs are much smaller than pine seedlings, competition for light can be excluded. The most plausible explanation therefore seems to be competition for some limiting nutrients.

The importance of soil moisture was directly evaluated in our irrigation experiment. Though physiological measurements (leaf water potential, stomatal conductance, net photosynthetic rate) suggested significant differences of stress in irrigated and non-irrigated pine seedlings during some intervals of both years of the experiment, there were no significant differences in relative stem diameter and height growth rates between irrigated and non-irrigated trees neither after the first nor after the second growing season (means of relative diameter growth rates for non-irrigated and irrigated trees over period 10/87 - 9/89 were 0.510 and 0.499 cm cm^{-1} y^{-1} respectively). This result is surprising especially because both hydrological years - 1987/88 and 1988/89 were rather dry in California (precipitation at BFRS was 37 and 12% below the long-term average). However, since

both study sites have relatively deep soils (>1.5 m), the results may partly reflect this circumstance.

ACKNOWLEDGMENTS

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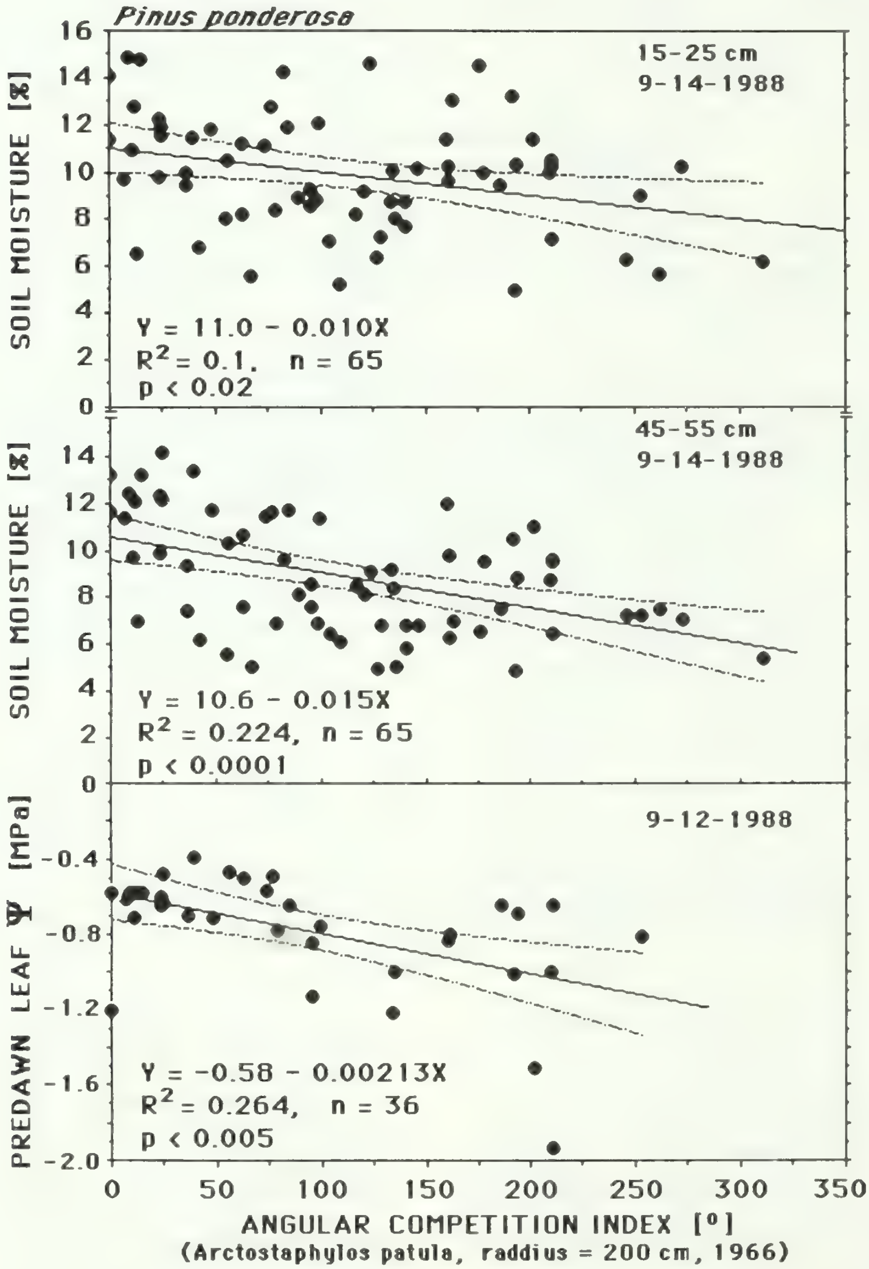
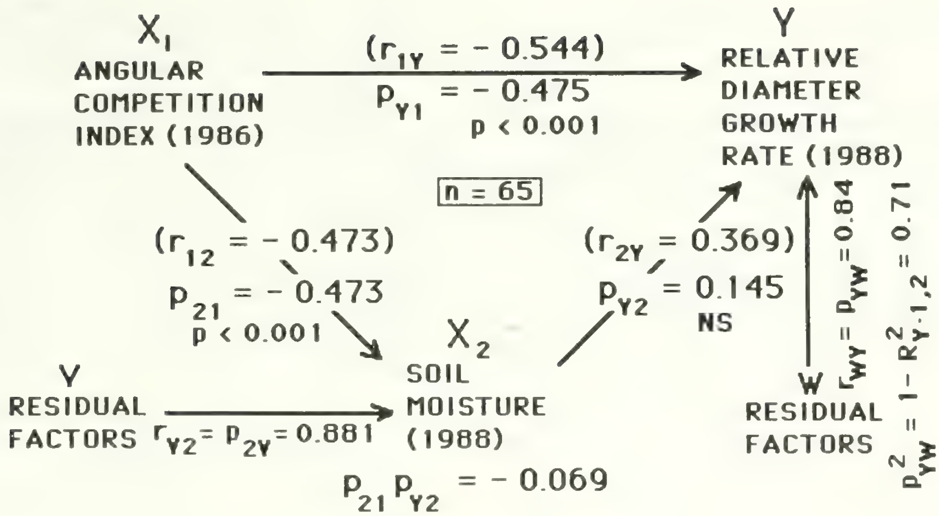


Figure 4.--Dependence of soil moisture (% by dry weight) and predawn leaf water potential of pondersoa pine on angular competition index for greenleaf manzanita in plots of 200 cm radius analyzed in 1986. Dashed curves indicate 95% confidence bands for the true mean of Y.



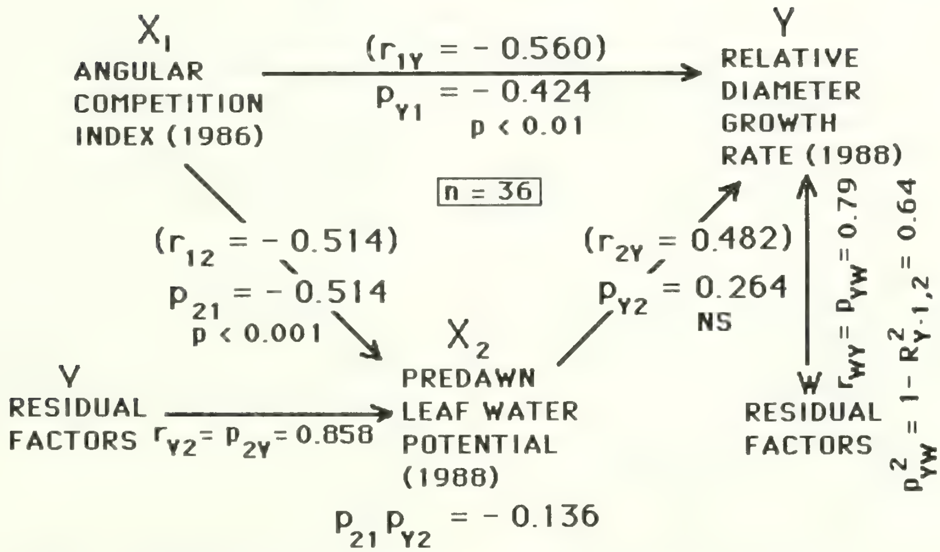


Figure 5.--Path diagram of the relationships between angular competition index (1986), soil moisture (1988) or predawn leaf water potential (1988), and relative diameter growth rate (1988). Path coefficients (p_{ij}) and products $p_{21}pY_2$ in particular indicate rather weak indirect effect of X_1 on Y (through soil moisture or through leaf water potential).

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Site Quality Estimates for Southwestern Ponderosa Pine[1]

William F. Stansfield and John P. McTague[2]

Abstract.-- In the Southwest site quality is generally estimated with site index. Other methods of estimating site quality from soil-site and plant community relationships are generally related back to site index; however their utilization in the southwest has been limited. Estimates of site index may be refined by including ancillary variables in the dominant height and site index equations.

INTRODUCTION

Site quality is defined by Clutter and others (1983) as the timber production potential of a site for a particular species or forest type. Estimates of site quality are generally obtained by estimating site index. However, estimates of site quality may also be obtained from soil-site relationships, and plant community relationships.

Several methods have been utilized to investigate site quality for ponderosa pine in the Southwest: site index, soil-site, and habitat type relations. The objective of this paper is to discuss such studies and examine them in regards to estimating potential productivity of a site.

SITE INDEX

Site index is commonly defined as the height of the average dominant tree at a specified index age. Thus, site index provides a quantitative estimate of site quality at a given point in time. In order to estimate site index at ages other than the index age, site index curves are developed. Such curves depict the expected average dominant height development pattern of the stand for a given site index (Clutter et al., 1983). In the Southwest site index curves developed by Meyer (1938) and Minor (1964) have been used.

The Meyer (1938) site index curves (fig. 1) are anamorphic; that is the system of curves all have the same shape, but differ in height by a constant ratio (Spurr, 1952). The height and age data used to construct these curves were obtained from temporary plots throughout the west. However, no data were obtained from Arizona or New Mexico.

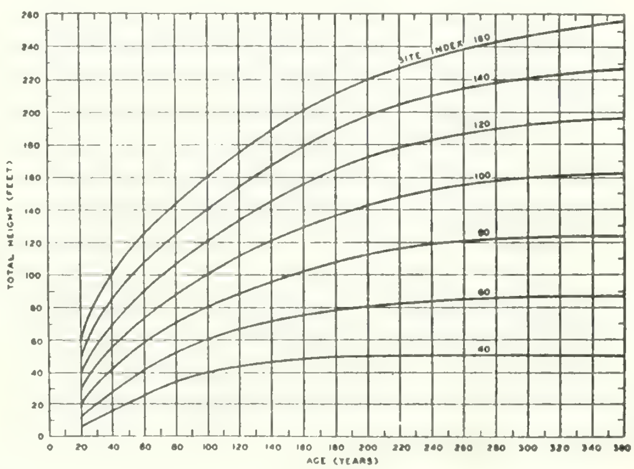

Figure 1.-- Anamorphic site index curves developed by Meyer (1938) for ponderosa pine.

In addition to the apparent problem of having no data from the Southwest, these curves are plagued by the problems of utilizing data from temporary plots to construct anamorphic site index curves.

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Inherent assumptions in the construction technique are (Spurr and Barnes, 1980):

1) The average site index is the same for each age class.
2) The dominant height growth rate is the same for all sites.

The first assumption implies that site index is not correlated with age. It has been noted (Beck, 1971a and Carmen, 1975) that often better quality sites will be supporting younger growing stock while poorer sites will be supporting older growing stock. Such a condition may exist due to past harvesting. In such instances site index is correlated with age, and the anamorphic site index curve, derived from temporary data, will be distorted and negatively correlated with age. Thus site index will be overestimated for young stands and underestimated for old stands. The second assumption implies that the rate of growth is the same for all sites. Several investigators have observed that this assumption is in error (Bull, 1931; Beck, 1971; and Carmean, 1972). On high quality sites the rate of height growth is typically greater for young dominant trees and tends to decrease as the tree ages. In contrast, young trees growing on low quality sites tend tohave slower initial height growth. However, as age increases the growth rates for trees on high and low quality sites tend to converge (Beck, 1971a).

In order to avoid the assumptions of anamorphism and the associated errors, real growth data is commonly employed in the construction of site index equations. Such data may be obtained from permanent plot remeasurements, stem analysis or internode measurements.

Minor (1964) developed polymorphic site index curves with real growth data obtained from north-central Arizona using stem analysis (fig. 2). Polymorphic curves are a family of curves which display different shapes for varying site qualities.

Minor (1964) utilized the parameter prediction method to construct a dominant height equation. The dominant height equation is expressed as:

$$H = S - 1.4003\,(A^{.5} - 10) + 0.1559\,(S)\,(A^{.5} - 10) \tag{1}$$

where
H = dominant height
S = site index
A = age at breast height in years.

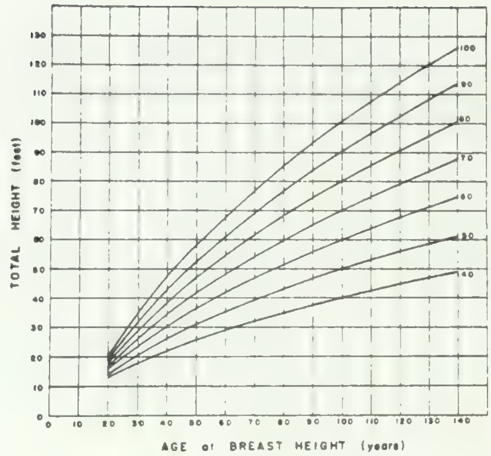

Figure 2.-- Polymorphic site index curves developed by Minor, 1964 for southwestern ponderosa pine.

The site index equation is obtained by inverting the dominant height equation such that site index becomes the dependent variable:

$$S = \frac{H + 1.4002(A^{.5} - 10)}{1 + 0.1559(A^{.5} - 10)} \tag{2}$$

Examination of equation (2) reveals that it is consistent with the definition of site index. When age at breast height equals the reference age of 100, dominant height and site index are equivalent. The curves produced, however, do not have an upper asymptote, and therefore are not recommended for use on trees greater than 150 years old.

The methodology utilized in the construction of dominant height and site index equations dictates their use in the field. Several salient features of the Minor site index curves deserve mention.

1) The site index equations are fitted to individual trees and not to an average tree per plot. Thus, the average site index of a stand is computed by determining a value of site index for each tree measured, and then by calculating a mean of the site index values.
2) Unlike most site index curve, the Minor equations are constructed from trees in only the dominant crown class. Therefore, codominants should not be selected as site trees. There is no need, however, to measure the tallest dominant tree in the stand. In addition, trees selected may be in dense clumps or isolated, since stand density does not have a significant

effect on dominant height (Minor, 1964; and Stansfield, 1989).

3) Minor used age at breast height rather than total age for the site index relationship. This procedure reduces the error found in other site index curves that arbitrarily correct for the number of years from stump to breast height.

Presently, all of the growth and yield simulators available in the southwest utilize site index as a driving variable. Three of the four simulators are calibrated to Minor's (1964) site index curves. RMYLD (Edminster, 1978) does calculate the average height of stand dominants and codominants to determine yield. The average height of dominants and codominants is calculated as a piece-wise function of total age and site index. The estimates of site index are obtained from Hornibrook's (1939) study of Black Hills ponderosa pine. Myer (1971) provided the following expressions:

for age less than 55 (3)

$$H = .01441(A)(S) - .12162(A) - 1.50953,$$

for age greater than 55 (4)

$$H = 10^{(0.59947 - 61.5019/A + 0.80522 (\mathrm{Log}\ S) + 20.525216 (\mathrm{Log}\ S)/A}$$

where

H = average height of dominant and codominant trees
S = site index
A = total age.

Utilization of equations (3) and (4) require the analyst to determine site index based on Hornibrook (1939), and not Minor (1964).

Site index, provides a quantitative approach to examine site quality, and uses the tree to integrate the factors which are required for growth. However, stand conditions may be such that estimates of site index are unreliable. Therefore, other methods that utilize soil-site factors or understory vegetation are also utilized to estimate site quality.

SOIL-SITE FACTORS

Relatively little research has been directed toward quantifying the effects of soil-site factors on site quality in the Southwest. In general, factors which are examined influence the availability of moisture and nutrients, as well as the trees physiological and evapotranspiration processes (Carmean, 1975). Coile (1938) suggested that aspect, slope, topographic position, texture and thickness of the A and B horizons, parent material and depth of the soil be considered when examining site quality. In addition, it is desirable that factors examined be readily identifiable in the field.

Williams et al., (1963) examined the effects of parent material, and chemical and physical properties of seven soils from the Zuni Mountains of New Mexico in regards to timber production. Williams et al., (1963) found that greenhouse fertility, surface permeability combined with depth of permeable soil, and available moisture-holding capacity of the surface soil were correlated with site index. Soils with high fertility, water-holding capacity, permeability of the A horizon and depth of the permeable soil had higher site index.

Senn (1976) examined site index in regards to soil type and parent material. Frequency distribution curves (fig. 3), developed by Senn (1976), for a range of site indices illustrate that site index variability for igneous soils in the Salt-Verde River Basin is related to

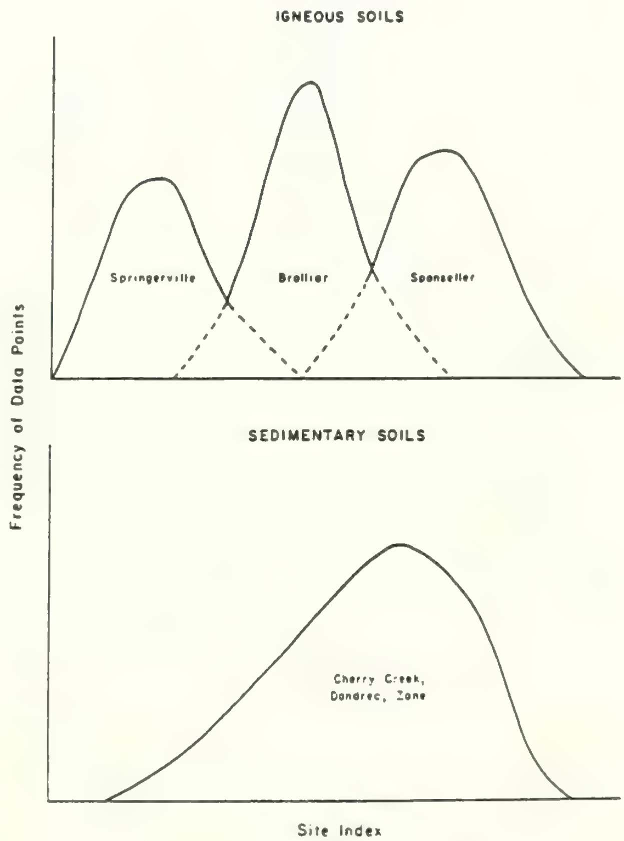

Figure 3.-- Relationship between site index and soil type (Senn, 1976).

differences in soil properties such as soil depth, infiltration capacity, and rockiness. As illustrated (fig. 3), distributions overlap at the lower frequency levels. Senn (1976) concludes that site index variation for sedimentary soil is not evident between soil types but rather within soil types. The site index variability is attributed to physiographic characteristics such as slope, aspect and elevation.

Minor[3] examined 18 soil-site factors and their relation to site index. He developed three linear models dependent upon parent material: sandstone, Kaibab Limestone, and Basic Igneous. The equations for each parent material are presented below.

Sandstone $R^2 = 0.46$ (5)

$$SI = 67.17 + 0.349(TH_{A+B}) - 0.163(SL)$$

Kaibab Limestone $R^2 = 0.58$ (6)

$$\text{Log } SI = 1.553 + 0.159(\text{Log } TH_A + 0.143(\text{Log } WP)$$

Basic Igneous $R^2 = 0.38$ (7)

$$SI = 85.41 + 0.476(TH_{A+B}) - 203.1(1/SP)$$

where
- SI = Site Index in feet (Minor, 1964)
- TH_{A+B} = Thickness of the A and B horizon (inches)
- Th_A = Thickness of the A horizon (inches)
- SL = Position on slope from base to top (%)
- WP = Winter Precipitation (inches)
- SP = Summer Precipitation (inches).

The explained variation provided by these equations are typical of soil-site regression equations used to estimate site index (Carmean, 1975).

Verbyla and Fisher (1989a) developed soil-site equations to estimate site index (index age 25). They advocate stratified random sampling for high and low quality sites will produce greater precision in estimating site quality from soil site factors. In their study they determined high quality sites to be from cool-moist habitat types with a high percent sand and a soil ph at 15 cm less than 6.55.

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[3]Minor, C. O. Unpublished research work. Soil-site site index equations for ponderosa pine based on parent material. personal communication. September. 1989. Flagstaff, AZ.

Verbyla and Fisher examined 32 possible variables including: aspect, solar radiation, elevation, as well as additional soil descriptors. However the final model for high quality sites, equation (8), was reduced to four variables and produced an adjusted R^2 of 0.49.

$$SI = 8.587 + 0.35(SA) - 0.064(SL) + - 0.091(SI)\ 0.009(P) \quad (8)$$

where
- SA = Percent sand at 15 cm
- SL = Percent slope
- SI = Percent silt at 45 cm
- P = Extractable phosphorus at 15 cm.

Brown and others (1974) have provided information concerning mean annual increment of ponderosa pine sawtimber yields for Brolliar and Siesta Sponseller soil types. Based on the results of simulation runs from PIPO, a growth and yield simulator, (Larson, 1975) sawtimber growth rates on Siesta Sponseller soils are more than twice that of Broillar soils over a range of basal areas 40 to 120 sq. ft. acre.

Larson and Minor (1983) have included soil type, based on parent material in an equation for predicting individual trees heights as a function of diameter at breast height and site index. The equation is:

$$H = 4.5 + b_0\ (1.9026(D) + 0.0287(D)(S)) - b_1\ (0.0403(D^2)\ (S - 70)^2 \quad (9)$$

where
- H = total individual tree height in feet
- D = dbh in inches
- S = Minor's site index
- b_0 = 0.892 basalt soil; 0.964 limestone soil; 1.143 sandstone soil
- b_1 = 0.740 basalt soil; 0.688 limestone soil; 1.300 sandstone soil

This equation produces greatest heights, for a give site index, on soils derived from sandstone parent material. Heights for basalt soils are typically the lowest, while limestone soils produce heights that are in the middle.

HABITAT TYPES

A habitat type is the collective area which is capable of supporting the same climax vegetation (Daubenmire, 1961). It is the basic unit in a site classification

system (Alexander, 1985) that utilizes the plant community as an integrator of environmental factors (Pfister, 1976). For timber management, habitat types have been suggested as indicators of site quality, silvicultural prescriptions, and physical and biological hazard ratings (Daubenmire, 1976).

Youngblood and Maulk (1985) delineated habitat types for ponderosa pine in southern and central Utah by productivity potential. Schubert (1974) has classified southern and central Utah into the Colorado Plateau physiographic province for southwestern ponderosa pine. Univariate statistics for site index by habitat type were provided. The mean site index and 95% confidence intervals for ponderosa pine are graphically displayed in figure 4. Inspection of means and

Figure 4.-- Ponderosa pine mean site indices and 95% confidence limits by habitat type for southern and central Utah. Data from: Youngblood and Maulk, 1985.

[a]Reference age is 50.
[b]"+" denotes the mean site index for each habitat type.
[c] the broken line represents the 95% confidence limits centered about the mean.

confidence intervals suggests that the difference in site index between habitat types is marginal. However, an analysis of variance and multiple range test must be performed to validate this hypothesis.

For southwestern ponderosa pine in New Mexico and Arizona, Mathiasen et al. (1987) did not find significant differences in mean site index between habitat types based on analysis of variance and multiple range tests. In a similar study, Mathiasen et al. (1986) found that mean site index for southwestern Douglas-fir in ten habitat types differed significantly, and that the habitat types could be separated into three distinct site quality classes. It should be noted that in each of Mathiasen's studies, both dominants and codominants were used to obtain site index estimates from the published curves. However, Minor's curves (1964) and Edminster and Jump's curves (1976) were constructed with only dominant trees. It is possible that by including codominants, site indices were underestimated and variances of the estimates were increased. In addition, Mathiasen et al. (1987) erroneously computed mean site index by averaging dominant heights and ages of the sample trees and computing a single site index estimate, rather than obtaining the site index of each individual tree and then averaging. If site trees were selected and calculations performed in a manner consistent with the construction of the site index curves, more definitive results might have been obtained.

Verbyla and Fisher (1989b) examined five habitat types is southern Utah in regards to ponderosa pine site index (base age 25). They found mean site index differed significantly among the five habitat types. They observed that the best ponderosa pine sites (site index greater than 7.2 m) occurred in the _Pinus ponderosa/Quercus gambelii_ and _Pinus ponderosa/Symphoricarpos oreophilus_ habitat types. However, within habitat type variation of site indices were broad, and therefore they recommended that habitat type should not be used alone in predicting the best ponderosa pine sites.

Daubenmire (1976) suggested that the shape of the dominant height curve may differ between habitat types. Monserud (1984) considered this hypothesis for Douglas-fir in the Inland empire; however, his data were obtained by habitat series. Monserud's results demonstrated that the shape of the dominant height curve did vary between habitat series, however, the differences were slight for stands under 70 years.

Stansfield (1989), similar to Monserud (1984), developed dominant height and site index equations for ponderosa pine on the Fort Apache Indian Reservation, in east-central Arizona. The equations incorporate habitat type groups and administrative unit as dummy variables. The dominant height equation was constructed from a sample of 147 dominant trees that were selected from 11 habitat types. The height/age pairs of each tree were determined with stem analysis, and fit to the King linear model, which contains three parameters. These parameters were then related to site index, habitat type groups and administrative unit. The dominant height equation is:

$$H = A^2/ C_1 + [(10000/(S - 4.5)) \{C_2 +(X_4* C_3) + (X1*C_4) + (X2*C_5) + (X3*C_6)\}] \quad (10)$$

where

H = dominant height in feet
A = age at breast height in years
S = site index (base age 100)
$C_1 = (-0.2937434511 - 0.25181744172*A + 0.00254798987*A^2)$
$C_2 = (0.18412315645 +0.00476897243*A + 0.00003392903*A^2)$
$C_3 = (-0.0665378094 + 0.00121985862*A + 0.00005543764*A^2)$
$C_4 = (-0.0708831617 + 0.00129952334*A + 0.000005905808*A^2)$
$C_5 = (0.03261381732 - 0.001413265*A + 0.0000108721*A^2)$
$C_6 = (-0.0413267842 +).00179908267*A + 0.0000137767*A^2)$
X_1 = 1 if habitat type is Pipo/Qugr Pipo/Mumo
0 otherwise
X_2 = 1 if habitat type is Pipo/Qugr, Pipo/Quga or Pipo/Mumo
0 otherwise
X_3 = 1 if habitat type is Pipo/Fear, Pipo/Muvi, Psme/Quhy, Psme/Fear, or Psme/Muvi
0 otherwise
X_4 = 1 if administrative unit is Northwest or Tribal
0 otherwise.

The site index equation is obtained by inverting the dominant height equation such that site index becomes the dependent variable. The equation may be expressed as:

$$S = 10000(H - 4.5) \{C_2 + (X_4*C_3) + (X_1*C_4) + (X_2*C_5) + (X3*C_6)\}]/[A^2 + (H - 4.5)*C_1 \quad (11)$$

where
all variables are as previously defined.

Figure 5 illustrates the dominant height relationship for ponderosa pine on the Southwest, Northfork and Maverick administrative units of the Fort Apache Indian Reservation for Pipo/Qugr and Pipo/Mumo habitat types.

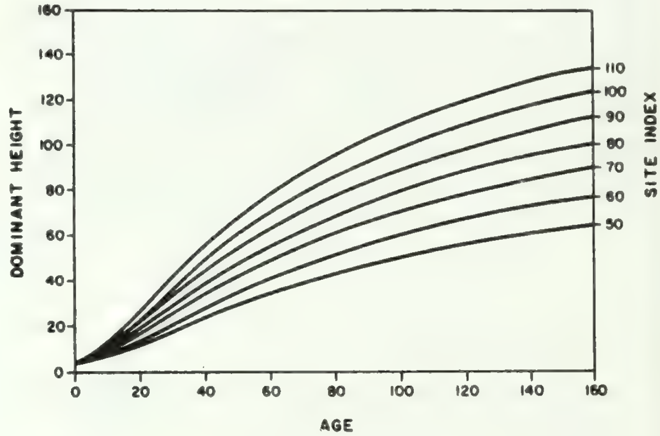

Figure 5.-- Ponderosa pine site index curves for the Fort Apache Indian Reservation (Habitat types Pipo/Qugr, and Pipo/Mumo; and Southwest, Northfork, and Maverick administrative units).

The ancillary variables, habitat type and administrative unit, assist in refining the dominant height curve by establishing different growth rates for any given site index. The effect of habitat type group on the dominant height curve for site index 80 is demonstrated in figure 6. Differences in growth rates are evident at age 20 and reach a maximum at age 50, approaching four feet. Beyond age 50 the growth curves converged at age 100. This behavior is consistent with the definition of site index. Beyond age 100 the growth curves diverge rapidly. The effects of administrative unit for Pipo/Qugr and Pipo/Mumo are illustrated in figure 7. Between administrative groups the difference in dominant height (site index 100) approached four feet at age 30. This difference continued although it was smaller at age 70. On lower quality sites the difference was less dramatic and converged slightly earlier.

SUMMARY AND CONCLUSIONS

Site index is the primary method used in the Southwest to evaluate site quality. Minor's (1964) polymorphic equations are

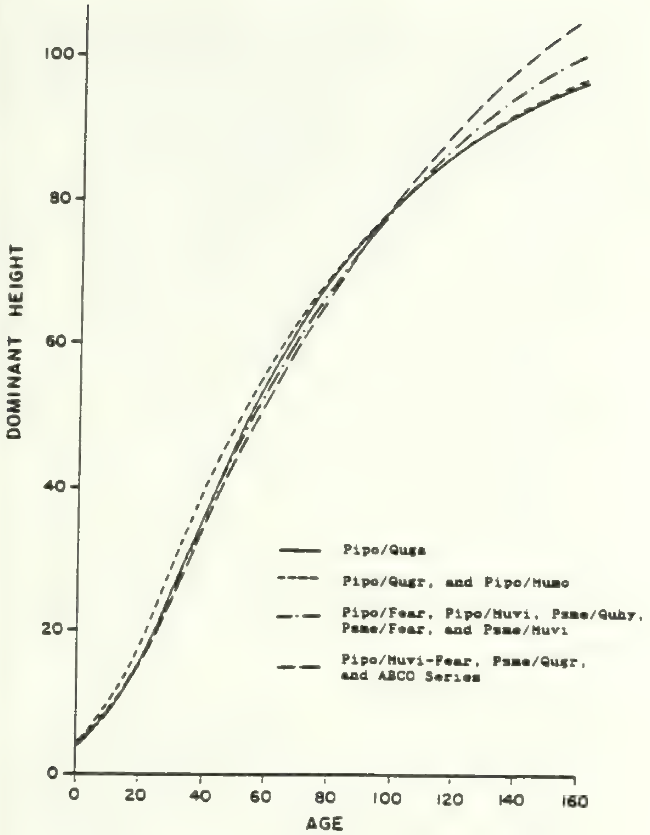

Figure 6.-- Ponderosa pine site index curves for the Fort Apache Indian Reservation (site index 80 - all habitat types groups; and Southwest, Northfork, and Maverick administrative units).

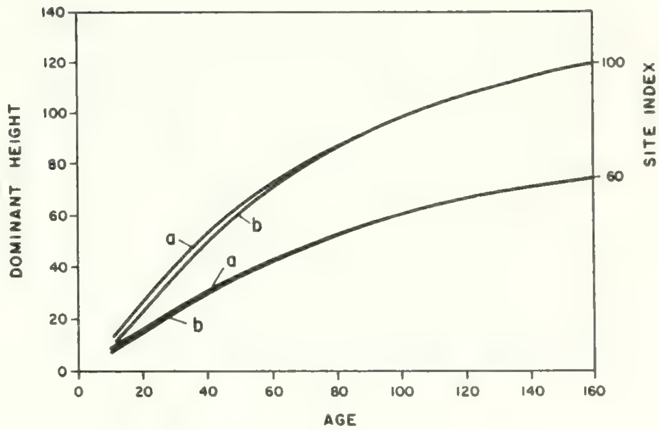

Figure 7.-- Ponderosa pine site index curves for the Fort Apache Indian Reservation (Habitat types Pipo/Qugr and, Pipo/Mumo by administrative unit).

[a]North section west unit and Tribal unit.
[b]South section west unit, Northfork and Maverick units.

the primary dominant height and site index equations used. However, site index and dominant height may be estimated with Meyer (1938) and the routine in RMYLD (Edminster, 1978). The latter methods are of limited utility since they were developed outside of the Southwest. The Meyer site index curves (1938) are also plagued by the assumptions of anamorphism as discussed previously.

Soil-site studies in the Southwest have generally attempted to regress soil and site characteristics to site index. Limited success has been realized by Minor (unpublished) and Verbyla and Fisher (1989). From the studies performed, the most important characteristics utilized in such studies infer the importance of moisture availability on a site. Examination of the sites water balance would be a useful to quantify the sites potential productivity. However, it is of limited practicality on an operational basis, due to the measurements needed to derive the water balance.

The use of habitat types in the southwest has been extensively examined. Investigators (Matheisian et al. , 1987; and Verbyla and Fisher, 1989) have not been successful in correlating individual habitat types with site index. Typically, the range of site indices within a habitat type are broad. However, groups of habitat type have been useful as dummy variables in describing the dominant height curve and estimating site index by identifying differences in growth rates (Stansfield, 1989).

One can expect that site index will continue to be the primary mechanism used to evaluate site quality. Use of ancillary variables that better define the growth curve should be included in future site index and dominant height equations. In the Southwest subdivisions within the Terrestrial Ecosystem Survey may be potentially important ancillary variables that can allow one to better evaluate site index and thus site quality.

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Methods for Testing the Wessin Variant of PROGNOSIS: Sensitivity to Simulated Ozone[1]

Terry D. Droessler[2]

Abstract.--The Western Sierra Nevada PROGNOSIS variant (WESSIN) projects tree and stand growth and yield for mixed-conifers in California. Elevated ambient ozone levels cause premature needle senescence with the greatest effects in the older needles of the lower crown. WESSIN growth equations contain live crown ratio as a predictor variable. Equation forms and parameter signs indicate how the model may perform in extreme conditions. WESSIN may also be tested by projecting ponderosa pine diameter growth, height growth and mortality for four 10-year cycles using four hypothetical live crown ratio levels in addition to the control.

INTRODUCTION

This work addresses methods to simulate ozone effects on ponderosa pine. The objective was to test the potential of WESSIN for simulating ozone damage via the live crown ratio variable.

The stand growth and yield model PROGNOSIS (Stage 1973; Wykoff 1986), was developed for use in the Inland Empire area of Idaho and Montana. Extensive testing and refinement of PROGNOSIS, and subsequent development of variants throughout the West, lend credibility to the growth and yield projections of the model. WESSIN (Dixon 1988), a variant of PROGNOSIS, was specifically designed to model tree and stand growth and yield for mixed-conifers of the Westside Sierra Nevada in California. It should be noted, however, WESSIN was not designed to model the effects of air pollutants on tree and stand growth.

The phytotoxic effects of ozone exposure on conifers are a characteristic chlorotic mottle, increased membrane permeability, premature leaf senescence and decreased photosynthetic capacity (Sharpe and Sheld 1986; Miller and Evans 1974; Reich and Amundson 1985). The greatest injury is generally in the older needles and the lower crown. Foliar injury has been found at 24 hour concentrations of 50-60 parts per billion (Miller et al. 1982).

Needle foliage is represented in WESSIN by a live crown ratio variable (the ratio of live crown length to total tree height expressed as a percent, hereafter referred to as crown ratio). Crown ratio is an independent variable in WESSIN diameter and height growth equations. The crown ratio model assumes a full cohort of needles, which for ponderosa pine generally consists of 5 age classes. Because ozone causes premature needle senescence, generally in the lower crown, the effect is hypothesized as a reduced crown ratio. This assumption implies a loss of foliage from the bottom of the tree only and is a simplification of ozone damage. Leaf area index or other crown variables would be preferable to model premature needle senescence. Live crown ratio, however, is the only crown variable in WESSIN.

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[1]Paper presented at the Multiresource Management of Ponderosa Pine Forests Conference at Northern Arizona University, Flagstaff, AZ, November 14-16, 1989.

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METHODS

Diameter and height growth in WESSIN are modelled as semi-empirical exponential equations. Diameter and height growth sensitivities to the crown ratio variable may be evaluated by inspection of growth equation forms and crown ratio coefficient signs. Model sensitivity is defined here as the difference in projections of diameter at breast height (dbh), dbh growth, height, height growth, total volume and number of trees for manipulated crown ratio levels. Crown ratio scenarios can be developed and rationalized, but model sensitivity may also tested by using crown ratio extremes.

A projection of four 10-year cycles may be appropriate. Cycle length should be based on 10-year height and radial increment data used to calibrate the model (Dolph 1988a,b). A 40-year projection period is considered an appropriate span to track model sensitivity to crown ratio changes. Five scenarios are being considered to simulate changes in crown ratio levels. The control scenario allows the model to cycle using the crown ratio prediction equation in WESSIN. If crown ratios are recorded in the field, they can be used as the initial values. The other four crown ratio scenarios follow. Crown ratios can be: (1) fixed at 95% over the cycles; (2) initially pridicted by the model and then reduced by 20% at the beginning of each cycle; (3) initially predicted by the model and then reduced by 20%, 25%, 33% and 50% for cycles 1-4, respectfully; and (4) fixed at 0% over the cycles. All species can be projected, but only the crown ratio of ponderosa pine trees could be altered.

The scenarios hypothesize "normal" growth by the control, two levels of reduced crown ratios and the extremes of near full and no live crown. The first reduced crown ratio scenario can be rationalized by assuming that ozone causes the premature senescence of the oldest age class of needles in the first cycle, the second oldest age class of needles in the second cycle and so on until all that remain after the fourth cycle are the current year needles. Because healthy ponderosa pine trees normally have 5 age classes of needles, this represents an approximate 20% per cycle decrease from what should have been present. For example, assuming an initial crown ratio of 50%, this scenario would result in 40%, 32%, 25.6% and 20.5% crown ratio for cycles 1-4, respectively. This reflects a decreasing reduction in crown ratio for each subsequent needle age class that dies.

Assuming the loss of an age class of needles per cycle, the second reduced crown ratio scenario decreases the crown ratio as a percent of the remaining age classes of needles in that cycle (by the last cycle, there are only two age classes of needles remaining, so the loss of the oldest age class results in a 50% reduction in live crown). The 95% crown ratio scenario can be considered as an upper bound reference and 0% crown ratio can be considered as a lower bound reference for dbh and height growth. The projections represent the full range of dbh, height, volume and mortality sensitivity to the crown ratio variable for a given dataset and stand conditions.

Figure 1 shows mean ponderosa pine tree crown ratio plotted by cycle for the five scenarios. From top to bottom: (1) crown ratio values were fixed at 95%, (2) control, (3) decrease predicted crown ratio values by 20% per cycle, (4) decrease predicted crown ratio values by 20%, 25%, 33%, and 50% per cycle and (5) crown ratio values fixed at 0%. Note the crown ratio scenario labelled control (model calculated) as compared to the four alternative scenarios.

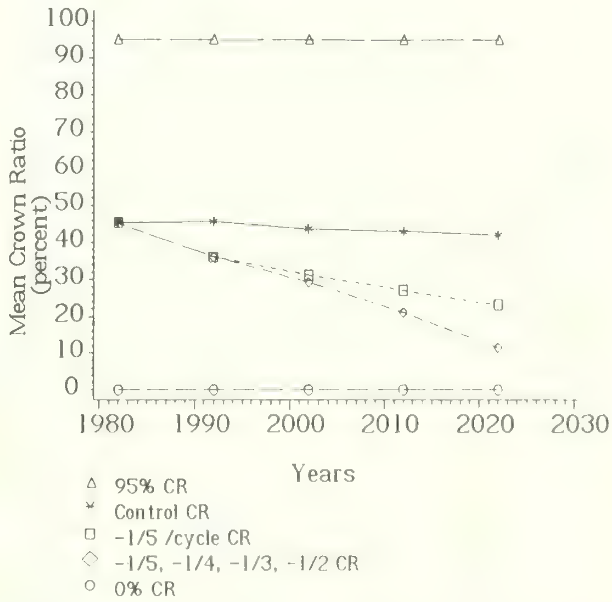

Figure 1. Mean ponderosa pine tree crown ratio plotted by cycle for the five scenarios.

EQUATION ANALYSIS EXAMPLE

Large tree diameter growth is modelled in WESSIN as a log-linear regression. Separate equations are used

depending on the availability of site index information. When assuming site index information is available, the following equation is the log-linear model for change in diameter growth squared.

$$\begin{aligned} Ln(dds) = LOC + c_1 * ELEV + c_2 * SL + \\ c_3 * SL^2 + c_4 * SITE + b_1 * Ln(DBH) \\ + b_2 * DBH^2/1000 + b_3 * CR + b_4 * \\ PBAL/(Ln(DBH + 1)/100) + b_5 * Ln(PBA) \end{aligned}$$

where:

DBH = diameter at breast height
CR = (lcr * lcr)/ Ln(DBH + 1)/1000
lcr = live crown ratio expressed as percent (0-99)
PBAL = basal area in larger trees on a given point
PBA = total basal area on a given point
LOC = location constant dependent on latitude
ELEV = average stand elevation in hundreds of feet
SL = average stand slope expressed as a percent
SITE = 50-year site index at breast height age

The dependent variable is the natural log of the change in inside bark diameter growth squared. Crown ratio appears as an additive independent variable multiplied by a positive coefficient. As crown ratio values decrease, the natural log of the change in diameter growth squared decreases. Because crown ratio is an untransformed variable in the equation, it can be zero without forcing diameter growth to zero. As crown ratio approaches zero, diameter growth decreases and death occurs in the field. However, even at very low crown ratios, diameter growth is often measurable. The equation is not conditioned to go to zero as crown ratio goes to zero and thus cannot reflect tree death at very low and zero crown ratio. All growth and mortality equations should be analyzed relative to the asymptotic properties and contribution of crown ratio.

DISCUSSION AND RECOMMENDATIONS

Empirical and semi-empirical growth equations can only be used within the bounds of the data from which they were developed. Leary (1988) states, "Analysis has been constrained by what could be done with available data, not what needed to be done. In addition to having too much data, one could argue that much of the data was for the wrong conditions - - too much in the middle range of predictor variables, and not enough at the boundaries".

Simply presenting the mean and range of a predictor variable is not enough. A calibration data table may imply, via the range of a predictor variable, that a wide range of data were part of the calibration dataset. If no or few extreme observations exist, the model will not behave properly at the extremes and cannot be applied outside the narrow range where the majority of the data exist. User's guides should be explicit in stating appropriate conditions for model use. Model users are the final arbiters. However, they must be given adequate guidelines to decide whether a model is appropriate for their particular research.

Some models can be conditioned to behave in the extremes or regions where no data exist. Often, several alternative models perform adequately. In many empirical applications, choosing a sigmoid model that has an appropriate inflection point and asymptote is important. Such a model is less vulnerable to aberrations or gaps in calibration data. Bunge (1967) stated, "Those modelling at lower (more aggregate) resolution levels would do well to select equations having a theoretical basis and having interpretable numerical constants, as well as goodness of fit".

Looking at the dbh growth equation, crown ratio could go to zero without forcing the natural log of diameter growth squared to zero. A naive solution might be to substitute the natural log transformation of crown ratio in equation (1) for the crown ratio predictor variable. By exponentiating both sides of the equation, the effect of the natural log transformation of the crown ratio variable is apparent. If crown ratio went to zero, the change in diameter growth squared would go to zero. The nonlinear equation would need to be fit directly, however, for the equation to exhibit this property.

Substituting natural log of crown ratio for crown ratio and exponentiating the equation is only a first step. All coefficients would need to be re-estimated by nonlinear least squares with the original calibration data. In fact, depending on how the equation was developed, new predictor variables or different transformations of existing predictor variables may be significant. Also, the crown ratio dataset needs to be supplemented with adequate samples near the extremes. Choosing equations with a theoretical and biological basis is important. Although it is possible for changes to be implemented, satisfactory results may be elusive. An empirical model sensitive to changes in crown ratio is still just an empirical model.

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Damage and Control of Diseases of Southwest Ponderosa Pine[1]

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Abstract.--Ponderosa pine is affected by an array of tree diseases in the Southwest. The most serious of these are dwarf mistletoes, root diseases, trunk decays, limb rust, needlecasts, and abiotic disorders (drought and winter drying). Research is ongoing to quantify the effects of diseases on various resource values including timber, recreation, scenic beauty, wildlife habitat, biodiversity, and water yields.

Diseases of ponderosa pine (Pinus ponderosa Laws. subsp. scopulorum E. Murray) have long been recognized as serious factors affecting forest productivity in the Southwest. Disease research was initiated concurrently with silvicultural studies on southwestern ponderosa pine. With the signing of a Memorandum of Understanding between the USDA Division of Forest Pathology and District III (now Region 3) of the Forest Service in 1910, a long period of forest pathology research on ponderosa pine began at the Fort Valley Experimental Forest and elsewhere in the Southwestern Region.

The major diseases of ponderosa pine throughout its vast range in western North America are discussed by Hawksworth and Shaw (1988). Lightle (1967) and Walters (1978a) describe diseases of ponderosa pine in the Southwest. In this discussion, we emphasize diseases that are currently of concern to forest managers in the Southwest.

Tree diseases seriously affect ponderosa pine forests managed for either timber production or recreation. Diseases discussed here include dwarf mistletoes, root diseases, rusts, trunk decays, needle and twig blights, and abiotic disorders. Diseases specific to nursery crops or natural seedlings are not included; readers are referred to a new handbook on nursery pests (USDA 1989) for this information.

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Even though diseases probably cause more damage to southwestern ponderosa pine than insects and fire combined, there are few quantitative data on losses. In addition to timber and recreation losses, diseases impact other resources such as wildlife habitat and scenic beauty. Data on these effects are also lacking, but the need for such information is increasing as foresters implement integrated resource management.

DWARF MISTLETOES

Southwestern dwarf mistletoe (Arceuthobium vaginatum (Wild.) Presl subsp. cryptopodum (Engelm.) Hawksw. & Wiens) is by far the most widespread and damaging disease agent of southwestern ponderosa pine (Korstian and Long 1922, Andrews and Daniels 1960, Hawksworth 1961, Hawksworth and Wiens 1972). The mistletoe occurs essentially throughout the range of ponderosa pine in Arizona and New Mexico, and also ranges north to Colorado and southern Utah; east to West Texas; and south to Sonora, Chihuahua, and Coahuila, Mexico. Southwestern dwarf mistletoe is also common on Arizona pine (Pinus ponderosa var. arizonica Engelm. = P. arizonica Engelm.) and Apache pine (P. engelmannii Carr.) in southern Arizona and New Mexico. In northern New Mexico, Rocky Mountain bristlecone pine (P. aristata Engelm.) is occasionally infected when growing near infected ponderosa pines. Other associated conifers are not parasitized by this dwarf mistletoe but they are hosts of other species of Arceuthobium. Nearly 40% of the commercial ponderosa pine type throughout the Southwest is affected by dwarf mistletoe (H. Maffei, personal communication), but infection is much higher in some areas, for example 70 percent on the Lincoln National Forest in southern New Mexico (Hessburg and Beatty 1986). Annual losses in ponderosa pine due to dwarf mistletoe in the Southwest are estimated at 20 million cubic feet (H. Maffei, personal communication).

Dwarf Mistletoe Effects

Dwarf mistletoe affects ponderosa pine forests in many ways:

They Reduce Growth

Dwarf mistletoes affect diameter, height, and volume growth. They typically do not affect height or radial growth until they invade the upper half of the crown. Disease intensity in trees is commonly assessed using the 6-class dwarf mistletoe rating (DMR)[3] system (Hawksworth (1977). In this system a tree with infection confined to the lower half of the crown would be Class 3. Growth is reduced markedly as the level of infection increases in the upper crown. For example, the last 5 years' radial growth of ponderosa pine in New Mexico was reduced 9% for DMR Class 4 trees, 23% for Class 5, and 53% for Class 6 (Hawksworth 1961). As a rule, a given mistletoe rating reduces height growth more than diameter growth.

They Increase Mortality Rates

Infection by ponderosa pine dwarf mistletoe, especially when severe, accelerates tree mortality (Korstian and Long 1922, Hawksworth 1961, Maffei 1989). Most ponderosa pines that are killed by dwarf mistletoe have a DMR of 6. Mortality in ponderosa pine stands in southern New Mexico was about 3% over 10 years for trees with a DMR of 3 or less, 9% for Class 4 trees, 12% for Class 5 trees, and 38% for Class 6 trees (Hawksworth and Lusher 1956).

In a more detailed study followed for over 30 years at Grand Canyon, Arizona, mortality was found to be related to mistletoe infection severity and tree size (Hawksworth and Geils 1990). Class 6 trees under 9 inches d.b.h. lived for an average of only 7 years while those over 9 inches lived for an average of 10 years. Comparable figures for trees in DMR Classes 4 or 5 were 17 years for small trees and 25 years for large trees. At Grand Canyon, Arizona, mistletoe-infected ponderosa pines were more readily killed by fire than uninfected trees (Harrington and Hawksworth 1989).

They Decrease Seed Production

Although quantitative data are limited, ponderosa pine dwarf mistletoe reduces cone and seed production. Korstian and Long (1922) found that the "reproductive value" (yield of seed per pound X number of seeds per pound X germination percent) of severely infected ponderosa pines in Arizona was about 75% less than that of comparable, uninfected trees. Myers (1974) recommends that ponderosa pines with a DMR of 4 or higher should not be left as seed trees.

They Reduce Wood Quality

Wood anatomy within dwarf mistletoe stem infections is markedly altered. No detailed studies have been conducted on ponderosa pine, but we may assume from studies on lodgepole pine that mistletoe-affected wood has tracheids that are shorter and distorted, with more ray tissues and consequently reduced strength (Piirto et al. 1974). The importance of this strength reduction is presumably slight since most of the affected wood is near the outside of the log and is removed in milling. Increased knot size and bole distortions caused by persistent brooms and trunk infections are probably more serious, but these effects have not been quantified.

They Predispose Trees to Attack by Insects

Ponderosa pines heavily infected with dwarf mistletoe are frequently attacked and killed by secondary bark beetles, primarily *Ips*. spp. (Parker 1979; Stevens and Hawksworth 1970, 1984). There have been few studies on interrelationships between dwarf mistletoe and *Dendroctonus* beetles in the Southwest, but mortality caused by *D. adjunctus* in southern New Mexico is directly related to the severity of dwarf mistletoe infection (Parker et al. 1975, Stevens and Flake 1974). Wagner and Mathiasen (1985) studied a pandora moth (*Colorada pandora*) outbreak on the North Kaibab Plateau and found that, while all trees were defoliated, mortality was concentrated in pines that were severely infected by dwarf mistletoe.

They Have Many Ecological Effects

Dwarf mistletoes influence several ecological relationships in ponderosa pine forests (Linhart 1988), including the rate and direction of stand succession. For example, some ponderosa pine stands in the Southwest are being replaced by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) because overstory pines are killed by dwarf mistletoe and immune Douglas-firs in the understory are released. When dwarf mistletoe kills groups of ponderosa pines, understory vegetation and microclimate in the openings created are markedly affected. The increased "edges" created by such openings may enhance the wildlife habitat value to some birds and small mammals.

Dwarf Mistletoe Control

Dwarf mistletoes can be effectively and economically controlled by cultural means (Beatty 1982b, Hawksworth and Shaw 1984, Johnson

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[3] For the DMR rating system, the live crown of a tree is visually divided into thirds and each third rated for mistletoe intensity as (0) for no visible mistletoe shoots or witches' brooms, (1) for light infection (less than half of the branches infected), or (2) for heavy infection (more than half of the branches infected). The ratings for each third are then added to obtain a tree rating, which ranges from "0" for a healthy tree to "6" for a tree heavily infected in each third. Ratings of all live trees (including uninfected trees) can be averaged to obtain a stand or plot rating.

and Hawksworth 1985, Scharpf and Parmeter 1978, Wicker and Hawksworth 1988), particularly even-aged cutting methods. Mistletoes are amenable to cultural treatments because:

(1) They are obligate parasites; that is, they require a living host to survive. Once an infected tree or branch is cut it is no longer a threat.

(2) They are generally host specific and usually attack one host or a group of closely related species. Resistant species can frequently be favored to minimize losses.

(3) They have long life cycles, i.e., the time from infection to seed production is 5-6 years, or longer. Long life cycles slow population build-up.

(4) They have a slow rate of spread. Seed dispersal distances are usually less than 50 feet from the tops of overstory trees and 20-30 feet from smaller trees. Added to its long life cycle, this limits rate of spread of dwarf mistletoe through even-aged stands to about 1-2 feet per year.

(5) They cause obvious damage. Damage due to dwarf mistletoe is readily apparent because of mistletoe plants, witches brooms, and declining or dead trees. Infested portions of stands can be readily delineated.

Various silvicultural treatments can reduce or eliminate damage caused by dwarf mistletoes. Clearcutting is the easiest to implement and more surely breaks the disease cycle between old and new stands. Where planting success is poor or unpredictable, shelterwood or seed tree methods may be preferable. However, shelterwood or seed tree cuttings will succeed only if infected seed trees are removed before they can infect the new, young stand. Infected seed trees should be cut before the young stand is about 3 feet high or, depending on site factors, about 10 years old. Small trees present little target area and thus intercept few mistletoe seeds (Wicker and Shaw 1967).

Silvicultural options are limited in mature, heavily infested stands where replacement is usually recommended. In diseased stands younger than harvest age, thinning will improve growth if infection severity is light and residual trees are not too heavily infected (Hawksworth 1978). The 6-class DMR system can also be used to quantify mistletoe severity in stands by calculating, from a representative sample, the mean DMR for all live trees, including non-infected ones. As a rule, stands with an average DMR over 3 should not be thinned (Hawksworth 1978). Usually the most severely infected trees (DMR Class 4-6) should be removed, even though they are frequently the largest, because their growth response will be limited, and dwarf mistletoe will intensify rapidly in them. The DMR system may also be utilized to help set cutting priorities, with the most heavily infested stands receiving early harvest entries.

Additional control techniques may be applicable in recreational or residential areas because of the high value of individual trees. These include pruning of branches and witches brooms, fertilization and supplemental watering, and also planting of non-susceptible species (Lightle and Hawksworth 1973; Scharpf et al. 1987, 1988). Beatty (1982a) gives practical guides for minimizing dwarf mistletoe damage and hazards in summer home sites in Arizona.

Recently, the growth regulator Ethephon (an ethylene-releasing agent) has been approved by the Environmental Protection Agency for limiting spread of dwarf mistletoes (Nicholls et al. 1987). Tests on ponderosa pine dwarf mistletoe at Los Alamos, New Mexico show it to be an effective therapeutant (Beatty et al. 1989). Ethephon does not affect the mistletoe's endophytic system within the host, but by causing the aerial shoots to fall off, it temporarily limits seed dispersal. Shoots will resprout from the established root system after 2 to 4 years, and re-application is necessary to prevent seed production. The chemical may be useful in high-value stands, such as in recreation areas, to protect understory trees from dwarf mistletoe.

Effects of dwarf mistletoe have been incorporated into the growth and yield model RMYLD for even-aged and two-storied stands of ponderosa pine in the Southwest and Central Rocky Mountains (Beatty 1982b, Edminster 1978, Walters 1978b). Models are being developed for uneven-aged ponderosa pine stands and for mixed conifer stands that include ponderosa pine (Edminster et al. 1990, Edminster and Hawksworth 1984, Maffei 1989).

ROOT DISEASES

Root diseases affect ponderosa pine in many parts of the West where annual losses from these diseases are estimated at 240 million cubic feet per year (Smith 1984). Even though breakdowns of this loss by tree species are not available, ponderosa pine likely contributes less to this figure than Douglas-fir and true firs because it is less often damaged by root diseases (Hagle and Goheen 1988). There is relatively little information on the root diseases of Southwestern ponderosa pine, and until recently they were thought to be of minor importance.

In the Southwest, Armillaria root disease, caused by one or more species of Armillaria, including A. ostoyae (Romagn.) Herink, (Wargo and Shaw 1985), is not uncommon throughout the ponderosa pine type, but damage is generally light (Wood 1983). A notable exception is in the Jemez Mountains of northern New Mexico, where Armillaria root disease causes extensive mortality in certain plantations (Weiss and Riffle 1971) and in one large natural forest that has been periodically logged by selective

cutting for over 50 years (Wood 1982). In this area, as commonly happens with root diseases, prior management activities seem to have exacerbated the problem.

Annosus root disease caused by Heterobasidion (Fomes) annosum (Fr.) Bref. also occurs on ponderosa pine in the Region (Mielke and Davidson 1947), but damage is again slight (Wood 1983). Black stain root disease, caused by Ophiostoma (Leptographium) wageneri (Goheen & Cobb) Harrington, has been confirmed on Douglas-fir and pinyon (Pinus edulis Engelm.) in the Southwest (Harrington and Cobb 1986); however, L. wageneri has not been confirmed on ponderosa pine (T. Harrington personal communication, 1989). Below are some brief descriptions of each of these diseases.

Armillaria Root Disease

Taxonomic and genetic research has identified several biological species and clones of Armillaria, but their relative pathogenicity and host specificity are poorly understood (Wargo and Shaw 1985). The fungus is easily recognized by the white mycelial fans and fungal, root-like structures called rhizomorphs found on dead and dying trees (Hadfield et al. 1986, Morrison 1981, Williams et al. 1986). Mortality may be localized, or extensive in ponderosa pine stands such as those in south-central Washington (Shaw et al. 1976, Shaw and Roth 1976) and northern New Mexico (Weiss and Riffle 1971, Wood 1982).

Mortality from Armillaria and other root diseases in ponderosa pine often is aggregated in disease centers, which enlarge over time (Wargo and Shaw 1985). Armillaria disease centers may spread outward by fungal transfer from tree to tree at a rate of up to 3 feet per year and survive for centuries (Adams 1974, Shaw and Roth 1976). This condition effectively puts portions of affected stands "out of production" for a rotation or longer because the fungus survives in the roots of infected trees and continually reinfects newly established regeneration (Shaw 1980). Logging often increases problems from this disease because roots on remaining stumps quickly become colonized, which increases the site's inoculum load (Shaw 1980). A recent study in Oregon (Filip et al. 1989) suggests, however, that normal precommercial thinning operations in ponderosa pine affected by Armillaria root disease will not increase damage from the disease.

Some general strategies for control of Armillaria root disease in ponderosa pine appear to be effective in at least one locale (Roth et al. 1977, 1980; Roth and Rolph 1978). One control strategy uses special marking guidelines for thinning and partial-cut harvest operations that call for "push-felling" and stump removal of all trees within a barrier of prescribed width around known infected trees. Another strategy calls for the removal of root systems of infected trees during harvest (Russell 1978).

These procedures remove inoculum from the soil, reduce the likelihood of new infections on individual trees, and limit spread of disease centers into healthy portions of the stand. Unfortunately, stump removal is expensive and its use is limited to certain soil types on rather gentle terrain. It is therefore necessary to determine the relative benefits that might accrue from root removal operations or implementing other control strategies. An experimental control operation by inoculum removal is scheduled for implementation next spring in the severely infested stands in the Jemez Mountains (Shaw, unpublished).

Knowledge of species susceptibility to Armillaria root disease is important to management. Over most of its range, ponderosa pine is less damaged by Armillaria root disease than are true firs or Douglas-fir (Morrison 1981). Foresters can utilize this differential susceptibility to reduce damage by favoring ponderosa pine in areas affected by Armillaria root disease. Such actions require caution and site specific information, however, because in certain areas (i.e. south-central Washington and northern New Mexico) ponderosa pine appears to be more susceptible to Armillaria root disease than Douglas-fir. Studies to evaluate the relative susceptibility of tree species native to the Jemez Mountains, where this disease is troublesome, are in progress (Wager and Shaw, unpublished).

Past trials on chemical control of Armillaria root disease in ponderosa pine have met with little success (Filip and Roth 1977, 1987). In contrast to annosus root disease, spores are of little significance to local disease development. Thus treatment of stumps to prevent surface infection by spores is impractical.

Annosus Root Disease

Annosus root disease, caused by H. annosum, occurs throughout the range of ponderosa pine. Root disease centers associated with pine stumps are reported from California, the Pacific Northwest, and the Northern Rockies; however, damage in Southwestern ponderosa pine is primarily seen as seedling mortality around infected stumps (Hawksworth, unpublished). In contrast, the fungus is not uncommon on large white fir (Abies concolor (Gord. & Glend.) Lindl. ex Hildebr.) in the Southwest (R. Gilbertson, personal communication). Detection of annosus root disease can be difficult unless the characteristic sporophores are present, or one is familiar with the white, spongy pocket rot and laminated decay (Bega 1978, Hadfield et al. 1986).

Like Armillaria, annosus root disease can kill trees in enlarging disease centers; however, unlike Armillaria root disease, spores of H. annosum are involved in disease spread and intensification. These spores are released from sporophores and carried by wind throughout the forest. Spores landing on freshly cut stump

surfaces germinate and produce fungal mycelia that grow down through stump wood and into lateral roots. Infections can develop on adjacent, live trees if healthy roots contact colonized stump roots--a process that may eventually lead to tree death and development of new disease centers (Hadfield et al. 1986). For this reason, treatment of pine stumps with borax to prevent surface infection by spores, and thus reduce the number of new infections that develop after logging (Graham 1971), is becoming a routine procedure in California, Oregon, and Washington. The utility of this control depends on the effectiveness of the borax treatment and the proportion of trees and stumps in the stand that were infected prior to logging. Local forest pathologists should be consulted if H. annosum is present at high levels in stands planned for silvicultural treatment. As with other root diseases, there is an increased concern with annosus root disease in recreation areas (Felix et al. 1974).

Current research on H. annosum suggests the existence of different host-specific variants or biotypes (Chase et al. 1989, Worrall et al. 1983). This host specificity provides an opportunity for disease control through planting trees resistant to the primary biotype present within an area. For example, a recent study in California (Kliejunas 1986) indicated that ponderosa pine seedlings could be planted with little risk from root disease around true fir stumps infected with H. annosum. Since H. annosum occurs on white fir and ponderosa pine in the Southwest (Mielke and Davidson 1947), knowledge of such host specificity may become useful to managers.

Black Stain Root Disease

Black stain root disease, caused by Ophiostoma (Leptographium) wageneri, occurs in scattered areas of ponderosa pine in California, the Pacific Northwest, and the Northern Rockies. This disease has not been confirmed on ponderosa pine from any location in the Southwest, even though isolates of Leptographium sp. pathogenic to ponderosa pine seedlings have been reported (Livingston et al. 1983). Although this disease was first described on ponderosa pine and pinyons (Wagener and Mielke 1961) and can be locally severe, it is of little consequence to management of either species in the Southwest. Black stain root disease also occurs on Douglas-fir in the Southwest, but is again of little concern (Harrington and Cobb 1986, 1988).

In ponderosa pine, black stain root disease causes symptoms similar to those caused by other root pathogens, including reductions in terminal and radial growth, needle chlorosis, and crown thinning (Hadfield et al. 1986). Black stain can be distinguished from other root diseases by the dark-brown to purple-black discoloration in the sapwood of the lower bole and root collar (Hadfield et al. 1986). The fungus grows in sapwood and plugs trachieds, which prevents water transport. Black stain root disease is a wilt disease that usually causes rapid tree decline and death (Hessburg and Hansen 1987). Unlike root diseases caused by Armillaria sp. and H. annosum, black stain root disease does not cause wood decay.

Leptographium wageneri can be vectored over long distances by root-feeding bark beetles and weevils. Hylastes macer has been identified as a putative vector of the disease on ponderosa pine (Harrington and Cobb 1988). New infections usually are initiated in low-vigor hosts since these beetles prefer, or are more successful at attacking, weakened hosts. Once the pathogen is established, however, it infects adjacent trees, irrespective of their vigor, via root grafts or by growing a short distance through soil (Goheen 1976, Hessburg and Hansen 1986, Hicks et al. 1980). The disease spreads at a rate of about 3 feet per year in ponderosa pine infection centers (Cobb et al. 1982).

Unlike Armillaria spp. and H. annosum, L. wageneri dies with its host. To survive and continue to spread to new hosts, the fungus requires a continuous network of living host roots. Where black stain root disease is a problem in ponderosa pine, control strategies have involved cutting all pine in a 50-foot buffer around infection centers and favoring alternate species in these areas (Hadfield et al. 1986). This technique is used because, like H. annosum, there are known variants of L. wageneri that exhibit a considerable degree of host specificity (Harrington and Cobb 1984, 1988). Interestingly, L. wageneri, Armillaria sp., and H. annosum can all occur in the same pine root systems (Filip and Goheen 1982).

Modeling Root Disease Behavior

To provide forest managers with a means to evaluate impacts of root disease in affected stands, and to project the effects of silvicultural operations on disease levels and stand production, a root disease model was developed for western coniferous forests (Shaw et al. 1985, Eav and Shaw 1987, Stage et al. 1989). At present, this model does not have functions for annosus or black stain root disease, although interest has been expressed in incorporating them (Shaw et al. 1989).

The model can, however, be used to predict effects of pathogenic Armillaria in stands of ponderosa pine or other conifers under various management regimes (Hawksworth and Shaw 1988). A keyword system allows users to input root disease inventory data, remove stumps, modify pathogen behavior, thin, and activate windthrow or bark beetle attacks. The model is attached to several variants of the Stand Prognosis growth and yield model (Wykoff et al. 1982). Through modification of the GENGYM growth and yield model (Edminster et al. 1990), it should be available soon for general use in the Southwest. The root disease model can be accessed via the Data General Growth and Yield

Submittal System of the USDA Forest Service (Sleavin 1989) by selecting the keyword "PEST" (Gladden 1989) from the Keyword Main Entry Menu.

A key element of the western root disease model is its ability to simulate interactions between root diseases and bark beetles. This feature is particularly important as root diseases rarely operate independent of other factors within a stand, particularly bark beetles. For example, in his survey of National Forests in the Southwest, Wood (1983) reported losses from root diseases as occurring in combination with either bark beetles or dwarf mistletoe or both. Livingston et al. (1983) also document interactions between root diseases and bark beetles in the Southwest.

The example of output from this model given by Hawksworth and Shaw (1988) for simulated plantings on a site with severe Armillaria root disease shows that ponderosa pine suffers less damage than Douglas-fir. The relative susceptibilities of these species can be changed in the model if local knowledge suggests they should. Research is in progress to clarify geographic and site hazard differences in species susceptibility to infection by and damage from Armillaria root disease.

STEM RUSTS

Limb rust is the most widespread stem rust of ponderosa pine in the Southwest (Mielke 1952, Peterson 1967). Two species of the rust occur in the Southwest. Cronartium arizonicum Cummins (Cummins 1984), which requires an alternate host (Castilleja spp.) to complete its life cycle, and occurs throughout most of the Southwest. The other, referred to in the literature as Peridermium filamentosum Pk., spreads directly from pine to pine. It occurs in northern Arizona and probably in northern New Mexico (Peterson 1967, 1968). Effects of the two limb rust species on ponderosa pine are similar: they cause no branch swellings but progressively kill branches as the fungus spreads systemically up and down the crown in the xylem of the bole and branches. When crowns have been seriously reduced by disease, trees die, usually through attack by secondary bark beetles. Baker et al. (1987) studied the disease in southern Utah and developed a system to rate severity of limb rust so that crown loss and mortality could be predicted. This system is being evaluated to quantify rust impact on the scenic beauty of affected trees and forests (Baker and Rabin 1988).

Western gall rust caused by Peridermium harknessii J. P. Moore (= Endocronartium harknessii (J. P. Moore) Y. Hiratsuka) is a widespread stem rust of hard pines in the western North America, but it only occurs in a few locations in the Southwest (Peterson 1967). The rust spreads directly from pine to pine without an alternate host (Peterson 1960, Riffle and Peterson 1986). As with limb rust, western gall rust has two forms, but these are distinguishable by gall morphology and aeciospore color (Mielke and Peterson 1967). Only the white-spored race has been confirmed on ponderosa pine in the Southwest. The orange-spored race was accidently introduced into the Flagstaff area in the early 1950's on experimental planting stock from Placerville, California. Clipping off all visible galls prevented the rust from becoming established in native pine stands (Hawksworth, unpublished). Western gall rust can kill young pines, but it causes more loss through log degrade associated with stem swellings and distortion.

Comandra blister rust (Cronartium comandrae Pk.) is a serious pathogen of lodgepole pine and ponderosa pine in the Pacific Northwest and Interior Mountain West (Johnson 1986). It occurs rarely in the Southwest, having been found on ponderosa pine in Arizona (North Rim of Grand Canyon, Flagstaff, and near Prescott). The rust requires an alternate host, bastard toadflax (Comandra umbellata (L.) Nutt.), to complete its life cycle. The rust causes fusiform cankers on branches and trunks. Stem cankers ultimately girdle and kill the tree. Recently, severe outbreaks of the rust have been found on the introduced Eldarica pine (Pinus eldarica Medw.) at Prescott, Payson, and Sedona, Arizona (Gilbertson and Rosemeyer 1985). Curiously, the rust is rare on ponderosa pines growing near infected Eldarica pines. The rust causes so much damage to Eldarica pine that this tree should not be planted near populations of bastard toadflax.

From a management standpoint, the most important consideration for stem rusts is to assure that severely infected trees are removed during intermediate entries.

FOLIAGE DISEASES

Needle disease damage is often spectacular, but epidemics are typically cyclic and cause little mortality or growth loss in natural stands. Severe damage is usually associated with favorable climatic episodes or planting of trees that are of non-local sources.

Several needle casts of the family Hypodermataceae are common on ponderosa pine in the Southwest, including Lophodermella cerina (Darker) Darker, Davisomycella ponderosae (Staley) Dubin, and D. medusa (Darker) Darker (Darker 1932, 1967; Keener 1962; Staley 1967). Lophodermella cerina is by far the most damaging. It has caused severe reddening of more than 250,000 acres of ponderosa pine on the Coconino and Prescott National Forests, Arizona from 1955 to 1962 (Staley 1967, USDA Forest Service 1961). The fungus damaged nearly 20,000 acres of ponderosa pine on the Mescalero Apache Reservation and Lincoln National Forest in southern New Mexico in 1987 (Rogers and Maffei 1988) and an additional 1,450 acres on the Cibola National Forest, New Mexico, in 1988 (Rogers and Maffei 1989). This needlecast

causes acute reddening of the previous year's foliage which is cast prematurely. When epidemics last over several years, such as in the Arizona case, trees survive with only their current year's needles. Needlecast damage is most noticeable in stream bottoms and along edges of meadows, but the actual growth loss and mortality have not been quantified.

Elytroderma blight (Elytroderma deformans (Weir) Darker) is the most widespread and damaging needlecast of ponderosa pine in North America (Childs et al. 1971). The disease was reportedly at "epidemic" levels in Arizona and New Mexico in the 1930's (Lightle 1967), but now occurs only locally in the Southwest and causes insignificant damage. The fungus causes premature death of one-year-old needles and formation of witches' brooms that are often mistaken for those caused by dwarf mistletoe. A characteristic symptom of this disease is brown flecks in the cortex at the base on infected needles. The disease is most prevalent in low, moist areas, at edges of meadows, and on sides of steep canyons. When defoliation continues for several years, trees are killed, as has occurred at Lake Tahoe in California (Scharpf and Bega 1981).

CANKERS AND TWIG DISEASES

Ponderosa pine is attacked by relatively few canker diseases. Atropellis canker (caused by Atropellis piniphila (Weir) Lohman) is common on ponderosa pine in southern portions of New Mexico and Arizona (Lightle and Thompson, 1973). The elongated, diamond-shaped trunk cankers are distinguished by dark fruiting bodies of the fungus and the blue-black stain in the sapwood behind cankers. Cankers kill small trees, but most degrade and loss is associated with stem malformations and discolored wood.

Twig blight or Prescott scale is not caused by a forest pathogen but the syndrome was studied for so long by Southwestern forest pathologists that we include it here. Twig blight is characterized by small branch mortality in ponderosa pine. Even though trees of all sizes are affected, the blight is most common on saplings. Twig blight was first noticed in 1919, and was studied for more than 30 years before the causal agents were identified. The primary cause is a scale insect, Matsucoccus vexillorum Morrison, but it is usually found in association with secondary fungi (McKenzie et al. 1948). In the 1930's, twig blight was considered to be a new and seriously threatening disease of ponderosa pine. The threat of extensive damage led to large-scale eradication operations even before the causal agents were known. Thousands of affected trees were cut and destroyed in southwestern National Forests by CCC crews. Intensive surveys of the ponderosa pine forests throughout the West were conducted, but twig blight was found to be essentially restricted to Arizona and New Mexico. Although outbreaks have been sporadic and local since 1934, twig blight incidence is currently increasing on the Chevelon Ranger District of the Apache-Sitgreaves National Forest and adjacent Fort Apache Indian Reservation in Arizona (Rogers and Maffei 1989).

DECAYS

Trunk rots cause serious volume loss in southwestern ponderosa pine, particularly in old-growth stands (Andrews 1955, Boyce 1961).

Red rot (also called red ray rot), caused by Dichomitus squalens (Karst.) Reid (= Polyporus anceps Pk.), is the major decay of living ponderosa pine in the Southwest (Andrews 1955, 1971; Long 1917). Andrews (1955) estimated that 15-25% of the gross volume in virgin stands in the Southwest is lost to red rot. The fungus commonly fruits on slash and sometimes on dead limbs of living ponderosa pine trees. Since bole infections emanate from infected dead branches over 1 inch in diameter with intact bark, branch pruning of the lower boles can reduce losses to red rot (Andrews 1955). Lightle and Andrews (1968) found that loss due to red rot in old-growth ponderosa pine on the Navajo Reservation in Arizona amounted to 15 % of the gross volume. The light selection harvesting system then used removed 48 % of the gross volume and reduced the volume loss to red rot to 9 % in the residual stand.

Red ring rot, caused by Phellinus (Fomes) pini (Thore.:Fr.) A. Ames, is the principal decay of ponderosa pine in Pacific Coast States and the Northern Rockies. It is rare on ponderosa pine in the Southwest, except for the Lincoln National Forest and adjacent Mescalero Apache Reservation in southern New Mexico (Lightle 1967). Even in these locations, red rot is more prevalent and damaging to old-growth ponderosa pine than is red ring rot.

Other decays of living ponderosa pine sometimes encountered in the Southwest are Fomitopsis officinalis (Vill.:Fr.) Bond. et Sing. (= Fomes laricis Jacq. ex Murr.), a brown cubical trunk rot; Phaeolus (Polyporus) schweinitzii (Fr.) Pat., a brown cubical butt rot usually associated with Douglas-fir; Veluticeps berkeleyi Cke., a dark brown cubical butt rot (Gilbertson et al. 1968); and Lentinus lepideus Fr., a brown cubical rot often associated with fire scars. Descriptions and keys to identification of these fungi and their decays are given by Gilbertson (1974), which describes more than 200 fungi that decay ponderosa pine in western North America.

ABIOTIC DISEASES

An array of environmental factors affect ponderosa pine throughout the West. These include climatic extremes, winter drying, top kill due to cold, frost damage to foliage, drought, salt toxicity, herbicide damage, hail damage, and air pollution (Miller 1978).

In the Southwest, periodic droughts are the primary abiotic factor affecting ponderosa pine. Several consecutive years of below normal rainfall in the 1950's led to the death of thousands of ponderosa pines in Arizona and New Mexico, usually in association with secondary bark beetles (Lightle 1967). Ironically, most mortality occurred just after the drought was broken and rainfall returned to near-normal levels and patterns. Plant-parasitic and mycorrhizal-parasitic nematodes were studied in ponderosa pines in drought-affected and non-drought stands in New Mexico, but results were inconclusive (Riffle 1967, 1968).

Lightning is a primary mortality factor in old ponderosa pine trees in many areas in the Southwest (Pearson 1950).

Winter drying, which is considered to be induced by drying winter winds when soil around the tree roots is still frozen, can cause spectacular damage to ponderosa pine and other southwestern conifers. Usually only the foliage is reddened and killed, but tree mortality may occur in severe cases. Winter drying affected about 150,000 acres of ponderosa pine and Douglas-fir in northern New Mexico in 1985, but most of the trees recovered (Owen 1986). Hail damage also can be severe in the Southwest: for example, on the Mescalero Apache Reservation in the late 1950's a severe hailstorm caused almost completely stripped ponderosa pine foliage on over 6,000 acres, and many trees were killed.

Ponderosa pine is quite susceptible to excess soil salinity (Spotts et al. 1972). Along roadsides where salt is used for deicing, needles frequently become discolored and trees die (Scharpf and Srago 1974, Walters 1977). Ponderosa pine is also seriously affected by air pollution in some areas, particularly by ozone in southern California (Miller 1978). Studies in Colorado suggest that Rocky Mountain ponderosa pine is more resistant to ozone injury than coastal ponderosa pine (Aitken et al. 1984). Little pollution damage to ponderosa pine in the Southwest has been detected to date. Surveys to evaluate sulfur dioxide damage to native forest vegetation in Arizona and New Mexico were conducted for several years by the Forest Insect and Disease Management branch of the Southwestern Region (Weiss 1974). Although unexplained needle flecking of ponderosa pine was found throughout the Southwest, this condition could not be attributed directly to sulfur dioxide emission sources, and no tree mortality resulted (Weiss 1974).

PEST COMPLEXES

The concept that a single forest pest acting alone kills trees is gradually being replaced by a realization that tree death typically results from complex interactions among pathological, entomological, and environmental factors. For example, *Armillaria* spp. often acts in association with other root diseases (Filip and Goheen 1982), and bark beetles can be attracted to ponderosa pines infected by root pathogens (Cobb et al. 1974, Lessard et al. 1985) or dwarf mistletoe (Stevens and Hawksworth 1970, 1984). The pest combinations reported by Wood (1983) and Livingston et al. (1983) emphasize the importance of these interactions as causes of tree mortality in the Southwest.

Much of the marking for selective harvest of old-growth ponderosa pine in the Southwest was based on classification systems originally designed to identify trees at risk to attack by bark beetles (Thompson 1940, Schubert 1974). Research is currently underway to determine if these high-risk trees are so categorized because of pre-existing root disease conditions (Shaw, unpublished).

CONCLUSIONS

Diseases have seriously affected the health and productivity of Southwestern ponderosa pine forests for millennia. In 1910, the USDA Division of Forest Pathology, in cooperation with the US Forest Service, began investigating diseases of ponderosa pine in the Southwest, particularly dwarf mistletoe and red rot. Dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodum*) affects nearly 40 percent of the ponderosa pine acreage in the Southwest and causes losses of more than 20 million cubic feet per year. Dwarf mistletoe, however, is amenable to silvicultural controls to minimize its effects in managed forests. Red rot (*Dichomitus squalens*) is the primary trunk rot of old growth ponderosa pine. Its importance is now limited because most old-growth stands have been entered.

Root diseases are serious in some cut-over stands of ponderosa pine. For example, *Armillaria ostoyae* is causing heavy mortality in northern New Mexico. *Heterobasidion annosum* causes some mortality in reproduction around infected stumps in southern New Mexico.

Limb rust (caused by two similar fungi, *Cronartium arizonicum* and *Peridermium filamentosum*), the only lethal rust disease of ponderosa pine in the Southwest, is more common in Arizona than in New Mexico. Atropellis canker (*Atropellis piniphila*) is common in some ponderosa pine stands in southern New Mexico, but damage is generally slight. Similarly, damage due to foliar diseases is generally minor, but can be spectacular, as in the 1950's epidemic of *Lophodermella cerina* that reddened ponderosa pine on over 250,000 acres in central Arizona.

Research on diseases of ponderosa pine is now concentrated on pest interactions. It is aimed at evaluating pest impacts on multi-resource values including timber, recreation, scenic beauty, wildlife habitat, biodiversity, and water yields.

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Wildlife Habitat Concerns: Moderator's Comments

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A major task of the Arizona Game and Fish Department is the effective coordination of wildlife habitat needs with commercial timber sales on Arizona's National Forests. The Department's Pinetop Region uses the concepts of interdisciplinary integrated stand management to review timber sales on the Apache-Sitgreaves National Forest. The diverse habitat needs of wildlife are being evaluated by emphasizing indicator species through wildlife habitat relationships models.

Forest fragmentation in northern Arizona, as a result of logging practices in the ponderosa pine-mixed conifer forests has forced black bears to use drainages inaccessible to logging or to small isolated islands of mixed conifers. As a result, female black bears are more vulnerable to hunting. A lack of recruitment of females to the population is hindered by the loss of cubs to predators. Habitat fragmentation threatens the viability of the bear population, and the situation needs to be monitored closely.

Guidelines developed for elk summer thermal cover in the Pacific Northwest are not applicable to southwest ponderosa pine or pinyon-juniper forests. Results from 64 documented cover sites obtained from 22 radio-collared elk indicates that a canopy closure of greater than 75% provides the best cover. A significant part of the high-quality cover was provided by Gambel oak.

Porcupines and Abert squirrels both consume parts of ponderosa pine trees, with the Abert squirrel being more specialized than the porcupine. However, feeding by both species is concentrated on specific trees. Patterns of utilization are different for the two species, so that individual trees are seldom fed upon by both. Evidence suggests that differential utilization of trees is associated with variations in levels of certain elements, carbohydrates, and monoterpene composition of resins.

In National Forest plans, "adjacency constraints" are defined stipulating that stands of a single age class cannot be adjacent to certain other age classes. The intention is to provide a diverse habitat for wildlife as forest regulation is accomplished. Strict adherence to constraints for enhancing horizontal and vertical diversity of tree overstory is not feasible. An index of spatial and temporal diversity may offer a simpler solution if well-defined deviations from adjency constraints are allowed to occur during a rotation.

Integrating Wildlife Needs into National Forest Timber Sale Planning: A State Agency Perspective[1]

Norris L. Dodd and Sharen L. Adams[2]

Abstract.--The Arizona Game and Fish Department (AGFD) has maintained a strong commitment to effective integration of wildlife needs into National Forest timber sale planning, particularly since the inception of Integrated Stand Management (ISM). This paper addresses AGFD timber sale coordination efforts on the Apache-Sitgreaves National Forests. Based upon the development of 56 sales since 1984, an evaluation of ISM sale planning is provided. Emerging timber management issues relating to applications of ISM which may impact wildlife integration of timber sales are addressed.

INTRODUCTION

The harvest of timber from National Forest timberlands has long been recognized as a viable and cost effective means to achieve desired wildlife habitat conditions and objectives (Thomas 1979, Hoover and Wills 1984). The key to effectively meeting the needs of a wide variety of wildlife species through planned timber harvest lies in the clear identification of issues and concerns, and translation of these into measurable objectives to be integrated through the sale planning process.

The Arizona Game and Fish Department (AGFD), through its aggressive Environmental Evaluation Program, has made a significant commitment to effective integration of wildlife needs in timber sale planning since the inception of its program 10 years ago. Timber management in Arizona is rapidly evolving, forcing habitat managers to monitor and evaluate past practices and address new issues and concerns. In addition, the complexity of achieving effective integration of timber sales is increasing dramatically, influenced by both biological and socioeconomic factors.

This paper addresses past and present integration efforts on the Apache-Sitgreaves National Forests, for which timber coordination efforts are the responsibility of the AGFD's Pinetop Region. The objectives of this paper are to:

1) detail Pinetop Region AGFD timber coordination and wildlife integration activities,

2) provide a preliminary evaluation of the application of Integrated Stand Management to timber sale planning since its inception,

3) identify and discuss newly emerging issues and concerns relating to current timber sale planning and implementation, and

4) present recommendations to ensure that timber management will continue to yield benefits to the wildlife resource.

ANALYSIS AREA AND MANAGEMENT BACKGROUND

The Apache-Sitgreaves National Forests (A-S NFs) are located in east-central Arizona, and encompass 810,826 hectares (2,003,552 acres). The two forests were proclaimed as separate

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forests in 1908, formed from the Black Mesa National Forest, itself established from the 1889 Black Mesa Forest Reserve. The two forests were consolidated administratively under a single Supervisor's Office in 1974.

The A-S NFs lie within the Colorado Plateau physiographic province, characterized by nearly flat bedded sedimentary rock generally bordered by the Mogollon Rim escarpment. The Mogollon Rim forms the southern boundary of the Sitgreaves NF and splits the Apache NF. Elevations range from 1704-3665 meters (5300-11,400 feet).

Landforms of the Sitgreaves NF are dominated by broad upland plains, hills formed from sedimentary deposits, and ridges and canyons formed by downcutting by tributaries of the Little Colorado River. The eastern portion of the Sitgreaves NF and entire Apache NF are more complex due to the prevalence of Datil volcanic fields. Landforms include upland plains, hills, ridges, scarps, mountains and numerous cindercone knolls. The Apache NF makes a significant contribution to the water needs of metropolitan Phoenix, as it is drained by the Little Colorado, San Francisco and Black rivers.

Vegetation of the A-S NFs is diverse due to wide variations in elevation, climate and soils. The most prevalent vegetative type is Ponderosa pine, which comprises 41% of the forests, followed by pinyon-juniper (38%), mixed conifer (8%), grasslands, both mountain (7%) and semi-desert (3%), and spruce-fir (2%) (USDA 1987). The forests support a tremendous riparian and fishery resource, though it comprises less than 1% of the land area.

The A-S NFs support 411 species of wildlife, relfective of the area's high vegetative, climatic and physical diversity. This assemblige includes 28 fish, 12 amphibian, 35 reptile, 242 bird and 94 mammal species (USDA 1987). Of these, 30 are afforded status as Federally- or State-listed threatened or endangered species (AGFD 1988a). Wildlife related recreation on the A-S NFs is significant, illustrated best by their status as fifth among all 156 national forests in cold water fishing recreation (Everest and Summers 1982). This fishing-related recreation contributes nearly $27,000,000 to local economics (AGFD 1986).

The A-S NFs yield the highest production of commercial timber of the 11 National Forests in Arizona and New Mexico, with an Allowable Sale Quantity (ASQ) of 99 million board feet (mmbf) per year. This ASQ represents a 53% increase over historic 10-year (1973-84) harvest levels (USDA 1987). Several large and small mills depend on commercial timber from the A-S NFs.

Management of the A-S NFs is guided by their Land and Resource Management Plan (USDA 1987), as mandated by the National Forest Management Act (NFMA). This controversial Forests Plan has focused considerable attention on management change on the forests, due partly to its strong emphasis on wildlife, fisheries, riparian and recreation. Through its setting of an ASQ well above historic harvest levels, the Forests Plan also maintains a strong focus on timber production on the forests. This plan was appealed in 1987 by six entities, including the AGFD, with the appeals remaining unresolved to date. Much of the focus of the six appeals relates to timber management of the forests, including the ASQ, old growth management and uneven- vs. even-aged management. Primary appellants concerned with such timber issues are currently involved in mediation in an effort to reach resolution.

Lastly, to gain a better understanding of both the relationships of biological and socio-economic influences on timber management on the A-S NFs, it is important to chronicle changes on the timber market as they relate to effective multiple resource integration of timber sales. At the time of the inception of Integrated Stand Management (ISM), a radical new approach to timber sale planning and implementation by the Southwestern Region (Arizona and New Mexico) of the Forest Service in 1984, the timber market was in an extremely depressed state.

Timber sales offered by the A-S NFs often went unsold, many under contract were not being cut until such time that the market rebounded, or were sold back to the Forest Service under its "buy back" program. Consequently, the ISM process proved highly successful in providing for the development of sales which creatively addressed multiple resource objectives and needs, with the emphasis on timber volume outputs being somewhat secondary.

However, in 1987 the timber market began a steady recovery, followed in 1988 by the first bidding and purchase of National Forest timber by the Fort Apache Timber Company (FATCO). FATCO had

historically relied totally on timber from the White Mountain Apache Reservation, located adjacent to the A-S NFs. Due to past cutting above sustained yield levels, and ongoing litigation with the Federal government, FATCO began successfully bidding and purchasing several sales on the A-S NFs in 1988 and 1989, with their stated desires to obtain 40 mmbf (40% of the A-S NFs' ASQ) off the Reservation. This served to dramatically alter the historic demand situation among traditional A-S NFs timber purchases.

Coinciding with the dramatically increased demand situation was the continually improving timber market, which served to further exacerbate the demand situation among purchasers on the A-S NFs. Up until this point, in mid-1989, many sales developed under ISM were realizing shortfalls in achieving Forests Plan volume targets on the order of 10 to 25%, and as high as 55%, reflective of effectively integrating multiple resource objectives, on-the-ground application of Forests Plan standards and guidelines, and actual available timber volumes.

At this point in time, with the unprecidented demand for timber from the A-S NFs and a strong timber market, the ability to continue to creatively develop sales with an emphasis on multiple resource objective achievement remains unclear. As will be discussed later, increasing emphasis is being placed on the attainment of timber volume targets and meeting the forests' ASQ. Such socio-economic considerations are now resulting in increased levels of conflict in timber sale planning and realization of new issues and concerns as sales developed under IRM are now being implemented.

DEPARTMENT TIMBER COORDINATION ACTIVITIES

The AGFD has long attempted to maintain a strong involvement and commitment to positive and proactive timber sale planning and coordination on Arizona's national forests. The Pinetop Region of the AGFD has interacted to a very high degree with the A-S NFs, particularly since the inception of ISM on the forests in 1984. Since formal adoption of Integrated Resource Management (IRM) as the Southwestern Region's project implementation and National Environmental Policy Act (NEPA) compliance process (USDA 1988), the Pinetop Region has interacted with the A-S NFs through this important vehicle.

IRM constitutes a 13-phase planning process by which Forest Service projects, including timber sales, are developed based upon key issues, concerns, and objectives, incorporating public involvement. In addition to the IRM process, AGFD timber coordination activities are conducted under authority of the AGFD-Forest Service Memorandum of Understanding, Sikes Act as amended in 1974, and specific Forest Service Manual supplements. Aggressive timber integration activities on the part of the AGFD are often perceived as going far beyond the traditional responsibilities of the state agency for wildlife and the Forest Service for habitat. The AGFD, through its committed habitat coordination endeavors, recognizes the inextricable link between effectively managing habitat and maintaining diverse and viable wildlife populations.

Critical to effectively influencing the outcome of timber sale planning from a wildlife perspective is having a strong understanding of the A-S NFs Forests Plan standards and guidelines. A crucial step in the IRM process is the initial scoping and identification of issues, concerns and objectives for wildlife for a specific proposed timber sale area. This information is crucial as it will ultimately drive the development of alternatives under IRM, and is obtained through extensive reconniassance of the sale area and documented in letter format.

The effective and clear setting of objectives for a wide range of wildlife species is also of paramount importance. The ability to set measurable or quantifiable objectives tied to current habitat conditions and wildlife species present is considered to have been a key element to effective integration of timber sales over the past 5 years under ISM. In attempting to quantify and document current and desired habitat conditions, AGFD personnel rely on intensive reconnaissance to make assessments of forage to cover relationships for big game, critical habitats (e.g. riparian, old growth), horizontal diversity and spatial relationships. Other factors such as road densities and fuels treatment integration needs are also considered.

One tool which has proven useful in quantifying existing habitat conditions is the Southwestern Region's Wildlife-Habitat Relationships Model (USDA 1984). This model allows for the assessment of habitat capability conditions relative to potential for "indicator species", based on intensive inventory of structrual stages (e.g. grass/forb, seedling/sapling,

pole, mature, old growth). This model has been modified continuously since 1985 to incorporate the best information available for the indicator or emphasis species, and better reflect the impact of conversion from uneven- to even-aged stands under even-aged management.

In spite of the limitations to utilizing a management indicator species approach to assessing timber sale relationships (Patton 1987), the wildlife-habitat relationships model has exhibited a high degree of utility in helping assess existing habitat conditions for a variety of species ranging from those often benefiting from moderate levels of timber harvest [e.g., elk (Cervus elaphus)] to those typically negatively impacted [e.g., goshawk (Accipiter gentilis)]. Clearly, managers cannot address the impact of timber harvest on all 411 wildlife species inhabiting the A-S NFs. The range of species for which existing conditions are assessed depends directly on those present within the specific proposed timber sale area and the level of concern raised during field reconniassance. Typically, objectives are identified and evaluated on each proposed sale area for a mix of early and late seral big game, small game, nongame and sensitive, threatened or endangered species.

The greatest utility of the wildlife-habitat relationships model and other assessments is in providing a baseline of existing conditions such that quantifiable objectives for timber harvest may be derived and compared during the alternative development phases of IRM. Limitations of modeling, particularly the inability to incorporate or display spatial relationships must be addressed through mapping and other analyses. Computerized Geographic Information System (GIS) analyses are just now being employed by the AGFD to help in evaluating timber sale alternatives.

The relative degree to which various timber sale harvest alternatives address key issues and concerns and meet quantifiable objectives serves as the basis for AGFD evaluation of such alternatives, as well as justifying the modification of alternatives to better address wildlife needs. In proposing its own alternatives or recommending the modification of existing ones, the AGFD has focused on the development of integrated alternatives as opposed to the development of pure wildlife alternatives. Such efforts have been largely successful due to the setting and attainment of wildlife objectives within the context of also meeting other resource objectives. Silvicultural needs are considered in the development or modification of alternatives, such as the treatment of high priority stands infected with dwarf mistletoe to create effective wildlife foraging areas.

Considerable complexity exists in timber sale planning under IRM where attempts are made to effectively integrate all resources, considering sawtimber harvest, commercial and precommercial thinning, road management, fuels treatment, post-sale Knutson-Vandenburg Act projects, old growth inventory and effective assessments of cumulative effects.

Should the IRM process fail to adequately address issues and concerns or document the selection of one alternative over others through NEPA environmental analysis, timber coordination may be relegated to more reactive measures (e.g., administrative appeal; AGFD 1989). The benefits of positive and proactive approaches to timber sale coordination have the potential to yield far more benefits for the wildlife resource than such reactive measures.

EVALUATION OF INTEGRATED STAND MANAGEMENT

Since the implementation of ISM in 1984 by the Southwestern Region of the Forest Service, representing a significant change over previous approaches to timber management, the AGFD's Pinetop Region has participated in the development of 56 sales on the A-S NFs. Of these, 12 have been carried through the final stages of implementation, with timber harvest completed by the purchasers.

Monitoring of these sales, as well as the insights gained from coordinating to a high degree in the development of all sales produced under ISM and IRM, affords the opportunity to assess the utility and value of these approaches to timber sale planning. All too often, management paractices and their results fail to be adequately monitored and assessed. However, in this case, with the controversies over timber management on the A-S NFs growing, monitoring of ISM applications is deemed essential if effective resolution of timber issues is to be attained.

ISM differs significantly from previous approaches to timber sale planning for several reasons. Most importantly, it is predicated upon the premise that all forest resources are intricately linked. Clearly stated

objectives for all resources, considered collectively, guide the development of harvest alternatives. This differs from earlier approaches, as timber goals and objectives typically drove the process, with other resources considered secondarily, usually through mitigation measures. The potential for success under ISM relates to the strong inter-disciplinary approach taken by the A-S NFs, involving all interested publics, including the AGFD.

Previous to ISM, timber harvest generally was applied to a majority of a particular timber sale area, often as high as 90% of the sale area. However, in most instances, particularly within the Ponderosa pine vegetation type, harvest levels were relatively light. These harvest regimes have often been referred to as "pick and pluck", and resulted in post-harvest conditions similar to that of individual tree selection under uneven-aged management systems. In general, relatively low volumes were yielded off relatively large portions of the timber sale areas.

With the advent of ISM, the harvest situation has been altered dramatically. First, treatments have been confined to a smaller portion of the timber sale areas, generally between 40 to 50% of the total forested acres. However, these areas are treated quite heavily, typically done from a pure silvicultural diagnosis stand-point. To date, nearly all treatments on the A-S NFs planned under ISM have been under even-aged management, with virtually no flexibility realized to even meet specific uneven-aged management objectives. Hopefully, this situation will be alleviated through amendment of the Forests Plan.

With the focus of timber harvest under ISM on even-aged management, the achievement of wildlife objectives has been addressed primarily through maximization of horizontal diversity and edge effect (Thomas 1979). In addition, a strong reliance on the relatively high proportion of the sale areas deferred from harvest has served to meet wildlife needs for old growth, thermal and hiding cover, vertical diversity, and has helped create effective mosaics of vegetation structural stages.

Under ISM, the vehicle for maximizing horizontal diversity with intensive even-aged prescriptions has been the limitation of stand sizes to 100 acres (La Follette 1981), with the exception of areas managed for old growth. Utilizing small stands, mosaics of moderate to heavily treated stands have been juxtaposed next to deferred stands to create effective forage to cover relationships. Edge effect has been maximized to create high levels of contrast between adjacent stands, dispersion of stands exhibiting differing structural conditions, and irregularity in shape. In these regards, ISM has proven successful in the vast majority of cases in achieving multiple wildlife objectives through the maximization of horizontal diversity and deferral of adequate old growth and cover areas.

Implied under ISM, with the emphasis on even-aged management and heavy silvicultural treatments, was adequate periods between reentry into sale areas to allow for growth of treated stands, regeneration of seed cuts to create new hiding cover stands, and effective wildlife use of created habitat mosaics. Forests Plan standards and guidelines stipulate, for instance, that adjacent stands exhibit 20 year age class differences. Where portions of large, homogeneous stands are treated heavily to create desired edge effect and structural diversity, induced diversity may be lost with subsequent heavy treatment of adjacent stands with insufficient time allowed between reentries.

Where it was believed that reentries into sale areas would be on the order of 12 to 15 years, or even 20 years, reentries into sale areas are already being planned as short as five years following previous harvest. With growing concern over the timber demand situation and efforts to meet the forests' ASQ, reentries into many sale areas have the potential to be dramatically hastened. Under the intensive silvicultural treatments programmed under ISM, residual stand basal areas are typically reduced to 30 to 40, with substantial effort made to convert uneven-aged stands to even-aged in a single entry. Consequently, the majority of treated stands will yield virtually no available volumes under shortened reentry periods. Hence, adjacent deferred areas then would appear to be the only place to seek volume to support the next entry. Also, due to the current designs being implemented for most integrated sales, premature reentry will eliminate diversity enhanced through the current entry and further reduce reservoirs of relatively dense, uneven-aged timber.

The premise that a relatively small proportion of the timber sale areas are treated intensively under ISM while retaining adequate amounts of untreated area to meet wildlife needs appears to be

unraveling as greater emphasis is again being placed on meeting increased timber demand. This then, represents the greatest potential threat to the ISM approach to timber sale planning, which has proven to be valuable in integrating the needs of a variety of resources into timber harvest.

EMERGING TIMBER ISSUES AND CONCERNS

After five years of planning and finally beginning to see implementation of timber sales developed under ISM on the A-S NFs, several important issues and concerns are now surfacing. Some represent issues which have arisen only recently, while others have faced resource managers for many years but are being heightened due to increased emphasis on meeting timber demands. These issues must be addressed at a variety of levels including research, effective project implementation, and resolution of appeals of the A-S NFs Forests Plan. Prompt attention must be paid to attempting to seek resolution such that adequate flexibility in forest resource management is maintained into the next century.

Major issues needing to be addressed relative to timber management include:

1) increasing emphasis on achieving the forests' timber ASQ to meet timber demand,

2) emphasis placed on even- vs. uneven-aged management systems,

3) increasing application of stand area designation marking in sale implementation, and

4) achieving effective integration of all timber management activities,

5) effective monitoring of timber sale implementation and impact on wildlife.

Increasing Emphasis on Achieving the Forests' ASQ to Meet Timber Demand

Under applications of ISM on the A-S NFs, the forests have been offering only approximately 90mmbf of their 99mmbf annual ASQ. This is largely a result of shortfalls realized in meeting the Forests Plan 10-year offering schedule target volumes. These shortfalls have occurred due to application of Forests Plan standards and guidelines, effective integration of multiple resource objectives, and actual available timber volumes being less than predicted. Nonetheless, with the timber market now very strong, coupled with the unprecidented timber demand situation on the A-S NFs, intense pressure is now being realized to meet timber volume targets and achieve the forests' ASQ. In fact, the ASQ, which is believed to represent a timber offering ceiling as set forth in NFMA, is now being considered as a commitment that must be met. Treating the ASQ as such now has the potential to have an impact on the creative development of quality timber sales under ISM.

Considerable attention is currently being given by the Forest Service to potential advancement of timber sales in the A-S NFs 10-year offering schedule to address the need to meet their ASQ. This is occurring despite the fact that the ASQ itself is a point of much contention in the ongoing Forests Plan appeals.

Concerns relating to the A-S NFs' ASQ include the cumulative or additive impact of the various levels of modeling used to generate the forests' ASQ and subsequent disaggregation to the 10-year offering schedule. The growth and yield model (ECOSIM) employed to drive the FORPLAN resource allocation model has been demonstrated to have numerous limitations (Belcher et al. 1982, McTague 1986). The FORPLAN model is further believed to have not been adequately constrained to account for adequate acreage managed for old growth, big game hiding cover, stand adjacency constraints, or uneven-aged management (AGFD 1988b).

Other concerns with the A-S NFs' ASQ relate to silvicultural limitations and Forests Plan standards and guidelines which may preclude meeting timber targets. The ability to meet nondeclining even flow requirements under NFMA is yet another concern with the current ASQ (AGFD 1988b). Consequently, considerable concern exists relative to the ability to maintain long-term community economic stability with current levels of harvest, and especially with potential advanced offering and harvest.

With the move toward an advanced timber offering schedule on the forests, coupled with the experience gained from numerous ISM applications, the AGFD harbors additional concerns relative to the forests' ASQ. Treating the ASQ as a "commitment" to industry will no doubt compromise the ability of ISM and IRM to produce quality projects which effectively address multiple resource objectives. There may be significantly increased cumulative effects with timber sale

offering advancement, including shortened periods between entries (as short as 5 to 7 years), resulting in the inability to meet wildlife standards and guidelines over time. In addition, concern exists over increased watershed degradation and ability to maintain viable and diverse wildlife populations.

The potential cumulative effects of past, present and future timber harvest on wildlife and other resources are just now being realized. Already, many sale areas for which sales have been developed or implemented are experiencing difficulty or inability to meet target volumes and Forests Plan standards and guidelines. With volumes maximized through heavy silvicultural treatments, such areas will not exhibit timber growth sufficient to support reenty within 10 to 15 years and still meet wildlife needs.

In many instances on sales currently being implemented, wildlife standards and guidelines are just minimally being met, particulary for harvest sensitive species such as the goshawk or Abert squirrel (Sciurus aberti). The Abert squirrel appears to be particularly sensitive to repeated entries under various silvicultural treatments which both open stands up and reduce or eliminate within-stand clumpiness or vertical diversity through even-aged management. Big game forage to cover ratios have often been minimally met under current timber sales developed under ISM, with effective cover becoming limiting. Without adequate time between entries, the cumulative effects of the next entry will be realized as wildlife standards and guidelines will be reduced below minimums. Advanced offering of sales to meet the ASQ will only exacerbate this situation due to shortened reentry periods.

The integrity of the A-S NFs' remaining old growth resource and biological diversity is also a major area of concern with potential advanced timber harvest. The Forests Plan ASQ was predicated upon liquidating much of the remaining old growth on the Apache NF and managing old growth on a "rotation basis" across both forests. However, both the Society of American Foresters (1984) and The Wildlife Society (Thomas et al. 1988) question the merits of creating, through silvicultural treatment, replacement stands of old growth to replace liquidated existing old growth. The impact of such proposed old growth management on dependent wildlife species (e.g., goshawk) is an area of particular concern. Alternative approaches to old grwoth management which retain existing reservoirs of biological diversity and management options into the future are a priority need.

Emphasis Placed on Even- vs. Uneven-aged Management Systems

As discussed earlier, ISM was predicated on predominately treating stands under even-aged management systems, such that horizontal diversity is maximized for wildlife. However, as sales have been implemented, the need for flexibility to treat stands under uneven-aged management systems has become apparent.

Southwestern Ponderosa pine forests typically developed over time as irregular uneven-aged stands (Pearson 1950), and associated wildlife species coevolved under such conditions. In fact, species for which information suggests that uneven-aged management is preferable include the goshawk (Reynolds 1983), Abert squirrel (Patton 1975), black bear (Ursus americanus; Mollohan 1987) and Merriam's turkey (Meleagris gallopavo; Phillips 1982). The Society of American Foresters (1981) has also promoted uneven-aged management as a means to maintain or enhance wildife values under timber harvest.

Uneven-aged management has been reported as a viable and economic method to manage Pondrosa pine forests and achieve multiple resource objectives (Schubert 1974, Hann and Bare 1979). Uneven-aged management is crucial to the management and creation of potential old growth, if such conditions can indeed be created. The current emphasis on even-aged management must be relaxed, with adequate flexibility available to practice uneven-aged management where appropriate. An approach where both even- and uneven-aged management systems are employed to create a mix of areas exhibiting horizontal and vertical diversity conditions now appears in order.

Increasing Application of Stand Area Designation Marking

With the intensive silvicultural treatments being applied under ISM, stand conditions are often dramatically altered in terms of structural diversity and age class mix. This is especially true under even-aged management treatments such as final removal and seed cut prescriptions. Many stands within integrated sales are now being implemented with stand boundary/area designation

marking (e.g., final removal of all trees 9" diameter at breast height and greater), where cutters are allowed to take all trees above the prescribed size. Individual trees in such stands are no longer marked for harvest by marking crews, nor are these crews providing the invaluable benefit of helping meet special wildlife habitat needs.

In the absence of specific efforts to survey and protect special wildlife habitat needs such as raptor nests, recruitment snags, turkey roosts, tree squirrel nest clumps, etc., these special features are not being located and protected under stand area designation marking. Such marking has constituted as much as 50 to 60% of some sale area treated acres. It is assumed that deferred stands will help address these needs, but as discussed earlier, once deferred stands are treated in the next entry, the special needs of wildlife will have been eliminated. Again, the intensive even-aged approach to harvesting timber may have potential long-term impact if these special wildlife habitat considerations are not adequately addressed.

Achieving Effective Integration of All Timber Management Activities

With the intensity of timber sale planning increasing on the A-S NFs, the need to achieve effective integration of all phases of silvicultural treatment has become evident. In the past, timber sales offering sawtimber were planned, sold and cut separately from pulpwood. Pulpwood was sold through the long-term Colorado Plateau Pulpwood Contract, which expired this year. Consequently, sales have been planned and implemented for sawtimber, with all post-sale activities completed, only to be reopened soon after for commercial thinning. This resulted in extending the periods under which the sale areas are subjected to harvest activities and associated impact to wildlife. This approach has also resulted in redundancy in timber planning and implementation, and has made effective integration and tracking between sawtimber and commercial and precommercial thinning difficult. Also, it has added considerably to cumulative impact to wildlife, fisheries, soils, watershed and other resources.

In several instances, objectives met for wildlife under sawtimber sale development have been negated at a later date when, for instance, stands deferred for hiding or thermal cover, were treated for pulpwood or precommercially thinned. Toward achieving effective integration of all silvicultural activities, comprehensive integrated planning must be accomplished. The ideal situation would be one where all silvicultural needs are applied through a single planning effort and entry. Such a situation would allow the sale to be closed out until such time that reentry is warranted, reducing cumulative effects and providing for cost-effective sale implementation. Hopefully, this issue will be adequately addressed through Forests Plan amendment.

Effective Monitoring of Timber Sale Implementation and Impact on Wildlife

Monitoring of Foress Plan implementation is a requirement for which inadequate resources or commitment have been realized. Monitoring is necessary to evaluate whether sale layout is achieved as planned, and whether special wildlife mitigation measures were provided for. It is also necessary to determine the degree to which habitat objectives were met with timber harvest.

Due to the reliance on the wildlife-habitat relationships model to assess habitat conditions and evaluate alternatives, timely monitoring and evaluation of the model should be accomplished. Without effective monitoring, the identification and ability to address new issues and concerns, such as those raised here, would not be possible. Increased emphasis must be given to monitoring timber sale implementation and the impact to the wildlife resource.

CONCLUSIONS

In spite of great strides made in achieving multiple resource objectives through timber harvest on the A-S NFs, considerable concern still exists surrounding timber management here. Timber management must be responsive to new issues and concerns, including incorporating the flexibility to apply uneven-aged management where needed, and not treating the ASQ in a rigid manner.

Under the intensive timber program on the A-S NFs today, the prospect of reduced abilities to maintain or enhance wildlife habitat conditions into the future are unclear, at best. The cumulative effects of past, present and future harvest and associated activities are a growing concern. With the prospect of advanced harvest to meet the forests' ASQ under heavy application of intensive even-aged

management systems, wildlife habitat diversity may be reduced.

With the current emphasis on maximizing horizontal diversity at the expense of vertical diversity through even-aged management, diversity needs will be adequately maintained on the short-term. However,with reentry into sale areas where deferred areas are treated prematurely, horizontal diversity may ultimately be reduced or eliminated on the long-term. Associated with this may be the loss of special habitat components, such as raptor nests, turkey roosts and the like, if adequate measures are not aggresively taken to ensure their protection under heavy timber treatment.

Many of the issues relating to the ASQ and management of old growth and how they may affect wildlife populations may be addressed effectively with the aggressive application of new decision support systems, such as Northern Arizona University's Terrestrial Ecosystem Analysis and Modeling System (TEAMS; Covington et al. 1988). Such a project level interdisciplinary model employing GIS and timber growth and yield capabilities, as well as the ability to integrate wildlife habitat constraints, shows considerable potential to help address complex timber management issues.

The complexity of timber sale planning is increasing rapidly, influenced by a variety of biological and socio-economic factors. Through committed proactive and positive efforts, the AGFD will continue its endeavor to ensure that National Forest timber sales are developed in a manner so as to yield benefits to Arizona's diverse wildlife populations.

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The Influence of Animals on Genetic Variability Within Ponderosa Pine Stands, Illustrated by the Effects of Abert's Squirrel and Porcupine[1]

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Abstract.--Mammals, insects and parasites can be important agents of natural selection in ponderosa pine forests. We illustrate the selective effects of animals by describing feeding patterns of the Abert's squirrel (*Sciurus aberti*) and the porcupine (*Erethizon dorsatum*). Each animal shows evidence of selective feeding upon specific host individuals. Both animals damage the trees they feed upon, and can therefore act as agents of natural selection. Because of their differential feeding patterns, these species can generate diversifying selection within stands.

INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Laws.) is a major contributor to the volume of lumber cut in North America. Because of this, management strategies have usually sought to maximize harvestable yields, and research has focused upon geographical areas which provide the greatest amounts of lumber: primarily stands in northern California, Oregon, Washington, Idaho, and western Montana. In other parts of its range, ponderosa pine is a much smaller, irregularly-shaped tree, and its contribution to local lumber industries is modest to non-existent. Its value in these areas has sometimes been overlooked.

Although many southwestern ponderosa pine forests produce modest volumes of timber, they are valuable in a variety of other contexts, and therefore must be managed for multiple uses, including watershed protection, recreation, and wildlife habitat. For example, the Rocky Mountains in Colorado give rise to five of the most important western rivers: the North Platte, South Platte, Arkansas, Rio Grande, and Colorado. Ponderosa pine forests are important components of these watersheds in many places. Furthermore, in Colorado, ponderosa pine-dominated stands comprise the forest zone most heavily used for recreation (Myers 1974). Natural forests that include native inhabitants, especially the more visible birds and mammals, are important in this context.

In this paper, we propose that the maintenance of genetic variability within ponderosa pine stands is essential to the health of these stands, and should therefore be a primary management objective. We relate the ecological complexity observed in these pine forests to their genetic complexity. To illustrate the relationship between ecology and genetics, we focus on feeding patterns of two mammals, Abert's squirrels (*Sciurus aberti*) and porcupines (*Erethizon dorsatum*). In the process, we suggest that diversifying selection can be generated by these herbivores within ponderosa pine stands.

In the next sections we discuss:

1. Factors shaping genetic variability in ponderosa pine
2. Abert's squirrel feeding patterns
3. Porcupine feeding patterns
4. Differential utilization of ponderosa pine phloem by Abert's squirrels and porcupines
5. Management implications

FACTORS SHAPING GENETIC VARIABILITY IN PONDEROSA PINE

Ponderosa pine has the most extensive geographic range of all North American conifers. The species has been separated into three major taxonomic entities, variety *ponderosa*, var. *scopulorum*, and var. *arizonica*. Increasingly, *P. ponderosa* var. *arizonica* is being recognized as a separate species, *P. arizonica* Engelm. (Conkle and Critchfield 1988). From biochemical, morphological and physiological perspectives, a total of five races have been identified: three are within *P. ponderosa* var. *ponderosa* (Pacific, Southern California, and North Plateau), and two are within *P. ponderosa* var. *scopulorum* (Rocky Mountain and Southwestern) (see Conkle and Critchfield 1988 for details). In mountainous regions, ponderosa pine is also differentiated elevationally, as documented in California (Callaham and Liddicoet 1961; Conkle 1973) and in Colorado (Mitton et al. 1980; Linhart 1988). On a local scale, stands on north- and south-facing slopes can consist of genetically-differentiated "aspect races" (Linhart 1988).

In addition to the large-scale geographic variability noted above, and discussed in more detail in Wang (1977), Friedman (1988), and Conkle and Critchfield (1988), there is a large amount of within-stand variation in morphology (Friedman 1988; Linhart et al. 1989), electrophoretically-detectable

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genetic polymorphism (Linhart 1988), and oleoresin chemical composition (Smith 1964; Linhart and Smith in prep.; Snyder et al. in prep.).

Traditionally, the study of genetic variation in forest trees has emphasized the roles played by physical gradients in shaping variability. Most studies have been "directional" in that they have documented the correlation between one or more tree characteristics and some factor (e.g. elevation or latitude) that affects tree biology in some predictable, linear fashion: trees from northern latitudes tend to have later dates of spring burst; trees from drier climates tend to develop larger root systems.

In the future, we need to pay closer attention to the role of biotic agents within stands. These agents are many. For example, almost 200 species of insects are reported to feed on ponderosa pine (Furniss and Carolin 1977) and there are probably more yet to be identified. These pine forests have also to contend with bacterial and fungal diseases, nematodes, dwarf-mistletoe parasites, and avian and mammalian seed, phloem and needle feeders (e.g. Fowells 1965; Baumgartner and Lotan 1988). For the sake of simplicity, we refer to this assemblage of herbivores, parasites, etc., as "dependent species." Two important facts must be recognized about dependent species: (1) each of them can generate natural selection, i.e. genetic change in forests; (2) several dependent species acting in concert can produce selection pressures in divergent directions. To elaborate, (1) natural selection occurs whenever a dependent species (a) reduces the fitness of a host individual by killing it or otherwise reducing its reproductive output, and (b) chooses individual hosts on the basis of host characteristics which have hereditary components. Forest trees and other plants have many phenotypic features which have, at least in part, some genetic basis. These include morphological features such as needle or leaf shape, thickness and pubescence, bark thickness, and physiological features including relative amounts of "attractive" compounds such as sugars and amino acids, or "repellent" compounds such as terpenes and tannins. The existence of significant genetic variability for many of these characters is documented in the plant breeding and forest genetics literatures (e.g. Allard 1960; Stern and Roche 1974; Dorman 1976; Wright 1976) and, at least for some characters, in ponderosa pine (Friedman 1988; Linhart et al. 1989). (2) Dependent species represent a variety of lifeforms, and therefore a diversity of physiological activities which can result in a diversity of host preferences. Differential host preference can generate diversifying selection. Examples of differential host utilization are reviewed in Linhart (1989) and summarized in table 1. Each of these examples documents the fact that individual trees or other plants possessing certain characteristics are attractive to a given dependent species and simultaneously less attractive to another dependent species. In other words, selection of individual host trees can be species-specific.

There are exceptions to this pattern, also discussed in Linhart (1989), as when *Leptographium* or *Arceuthobium*-infested ponderosa pine are simultaneously attractive to porcupines. However, there is much evidence to suggest that what makes a host tree attractive to e.g. a fungus, an insect, or a mammal involves specific features of host phenotype, presumably because of physiological constraints and requirements of the dependent species.

Given the large numbers of dependent species feeding upon forest trees such as ponderosa pine, the diversifying selection generated is "multi-directional," and may be at least partially responsible for the high levels of genetic variability documented in this and other tree species (Hamrick et al. 1979; Linhart 1989). When different dependent species differentially utilize specific host individuals on the basis of these hosts' genetically-determined phenotypic traits, and thereby differentially affect host fitness, diversifying selection occurs within stands. Data are still too scant to demonstrate that each of the major dependent species that damage ponderosa pine contributes to diversifying selection. To illustrate how dependent species can generate diversifying selection, we focus below on two mammals that both feed on ponderosa pine phloem.

ABERT'S SQUIRREL FEEDING PATTERNS

The tassel-eared, or Abert's squirrel (*Sciurus aberti*) is restricted to stands of ponderosa pine in Colorado, New Mexico, Arizona and Utah in the U.S., and along the Sierra Madre Occidental to southern Durango in Mexico (Diersing and Hoffmeister 1978). It is dependent upon ponderosa pine trees for food and nest sites (Keith 1965). The squirrel's diet varies seasonally with the availability of various food items, but consists almost entirely of tissues from ponderosa pine and other species which occur in close association (often symbiotically) with it. Abert's squirrel is thus considered a food-specialist.

Along the Colorado Front range, observations by M.A.S. indicate that during the summer months and continuing into autumn, the squirrels feed heavily upon the seeds of developing ovulate cones, when available, as well as upon a variety of hypogeous and epigeous fungi. The seeds of ponderosa pine are high in nutritive value, and Abert's squirrels can reduce the cone crop up to 75% (Larson and Schubert 1970). From autumn until well into spring, the diet is composed primarily of inner bark (mostly phloem) stripped from ponderosa pine twigs. In spring, staminate cones and apical buds of ponderosa pines are also important food items. These observations are generally consistent with those reported by other investigators from various parts of the squirrel's range (Keith 1965; Farentinos 1972; Stephenson 1974; Hall 1982; States et al. 1988). In Arizona, where Gambel oak (*Quercus gambelii*) is a common associate of ponderosa pine, Stephenson (1974) reported that acorns of this species, when available, can comprise up to 40% of the autumn diet. Hall (1981) refers to a number of miscellaneous (uncommon) food items, including seeds of other conifers and lupine, leaves of New Mexican locust, and mistletoe. Occasional feeding on carrion (Keith 1965) and gnawing of shed antlers (Keith 1965; Hall 1981) have also been reported.

Ponderosa pine phloem, the primary (at times sole) food item taken in winter, is of poor nutritional quality (Patton 1974) compared with other foods utilized by the squirrels. Low in protein and fat (Patton 1974), it contains appreciable quantities of monoterpenes, a group of secondary plant metabolites with deterrent effects upon a number of herbivores (Farentinos et al. 1981; Denno and McClure 1983; Reichardt et al. 1987). Phloem-feeding, always the winter mainstay of Abert's squirrels, may be especially important in years of poor cone production, when reliance upon phloem begins earlier (Goldman 1928; Bailey 1931; Keith 1965; States et al.

Table 1. Examples of differential host utilization. Intraspecific variability in a host plant is associated with interspecific differences in host preference by species of parasite or herbivore (i.e. dependent species).

Host Species	Dependent Species	Preference Pattern	References
Pseudotsuga menziesii	Deer (*Odocoileus hemionus*) Hare (*Lepus americanus*)	No correlation between herbivore spp. in preference for specific clones	Dimock et al. 1976
	Wooly aphid (*Gilletteella cooleyi*) Needle cast fungus (*Rhabdocline pseudotsugae*)	Populations resistant to aphid are susceptible to fungus	Stephan 1987
Pinus radiata	*O. hemionus* Porcupine (*E. dorsatum*)	The herbivores prefer different clones	Hood and Libby 1980
Camellia sinensis	80 spp. of phytophagous insects	Guilds which vary in feeding patterns prefer hosts with different leaf characters	Banerjee 1987
Pinus ponderosa	*O. hemionus* Rabbit (*Sylvilagus nuttalii*) *E. dorsatum*	*O.h.* and *S.n.* prefer trees of same origin. *E.d.* preferences very different	Squillace and Silen 1962
	O. hemionus Wooly aphid (*Pineus coloradensis*)	Feeding tree distributions show no significant correlation	Linhart in prep
	Porcupine (*E. dorsatum*) Squirrel (*S. aberti*)	*E.d.* and *S.a.* feed on trees with different resin and phloem characteristics	Habeck in prep Snyder in prep
Pinus contorta	*Arceuthobium americanum* *Dendroctonus ponderosae*	Mistletoe-infected trees are less susceptible to beetle attack	Hawksworth and Johnson 1989

1988), and in years of heavy snow cover, when the animals may be prevented from foraging for higher-quality foods. Abert's squirrels cache very little or no food (Keith 1965), and must feed daily (Golightly and Ohmart 1978), even in inclement weather. Stephenson and Brown (1980) presented data which correlate snow cover with squirrel mortality, and suggested that prolonged reliance upon phloem might be responsible.

Apparent preferences for particular, individual trees as sources of phloem (referred to henceforth as target trees) have been noted by a number of investigators (Goldman 1928; Pearson 1950; Keith 1965; Farentinos 1972; Pederson et al. 1976; Capretta and Farentinos 1979; Hall 1981; Pederson and Welch 1985). Target trees are visually indistinguishable from nearby trees which are not utilized as sources of inner bark (non-target trees) and, along the Colorado Front Range, account for a relatively small percentage (<10%) of trees in stands which support squirrel populations. There has been considerable interest in determining the basis for this apparent selectivity. Because target trees do not differ significantly from nearby non-target trees on the basis of such characteristics as size, age, solar exposure, etc., research efforts have concentrated largely on biochemical differences between them. Below, we summarize the biochemical work published to date.

As early as 1965, Keith (1965) suggested that Abert's squirrels may select target trees which taste better or are higher in nutritive value. Hall (1967) suspected that target tree phloem might taste sweeter, and subsequent analyses by Thomas (1979) supported this idea. Capretta and Farentinos (1979) reported that their preliminary data showed no apparent differences in sugar content between target and non-target tree phloem, but suggested that target tree phloem may contain significantly higher amounts of proteins and lower levels of monoterpene hydrocarbons. Farentinos et al. (1981) reported that twigs from target trees contained smaller amounts of monoterpenes, and that captive squirrels avoided food laced with high amounts of alpha-pinene (a monoterpene found in ponderosa pine tissues). Pederson and Welch (1985), however, found no difference between monoterpene levels in target and non-target trees, and suggested instead that squirrels prefer trees with inner bark that is easily peeled from twigs. Hall (1981) analyzed oleoresin for monoterpene

composition, and found no significant differences in amounts of individual monoterpenes between target and non-target trees.

Despite evidence that taste is more important than natural contextual cues (e.g. the presence of conspecifics, etc.) in mediating patterns of target tree utilization (Capretta et al. 1980), the biochemical bases of target tree selection have not been clearly demonstrated. Factors mediating target tree selection are currently being examined along the Colorado Front Range, and a partial summary of results is included in table 2 (Snyder in prep.).

PORCUPINE FEEDING PATTERNS

The porcupine (*Erethizon dorsatum*) ranges throughout North America, primarily in forested regions. It is a classic example of a generalist herbivore and its diet may vary dramatically from season to season and among habitats. A typical summer diet consists of herbaceous plants, tree seedlings, foliage and fruits. During the winter, porcupines usually eat inner bark, conifer needles and dwarf-mistletoe (Brander 1973; Dodge 1967; Spencer 1962; Taylor 1935; Woods 1973).

There is indirect evidence that porcupines may utilize individual trees based, in part, upon concentrations of nitrogen (Cabanac 1977; Roze 1989), phosphorus (Stricklan et al. 1983), fiber (Stricklan et al. 1983) and sodium (Roze 1989). These traits can reflect differences in physiology (e.g. rate of ion uptake from soil) which are known to have a genetic component in certain species (Allard 1960; Antonovics et al. 1971), although nothing is known about this for ponderosa pine.

Ponderosa pine phloem is a principal winter food source for porcupines in the western U.S. Within populations of ponderosa pine, porcupines often eat the phloem of some individuals repeatedly while other trees remain untouched. Many people have reported that within mixed-aged stands, target trees could be differentiated from non-target trees based upon their size class and/or vigor. Most target trees appeared to belong to the pole-sized diameter class of about 10 to 25 centimeters (4 to 10 inches) (Curtis and Wilson 1953; Van Deusen and Myers 1962; Storm 1962; Smith 1975). Young, pole-sized trees are often fast-growing and therefore contain higher levels of fats and carbohydrates than slower-growing trees (Harder 1980; Krefting et al. 1962; Shapiro 1949; Taylor 1935). It is not clear to what extent tree vigor in the stands studied is simply a function of age and resource availability; it is known to have a genetic component in ponderosa pine in certain situations (Friedman 1988; Linhart and Mitton 1985).

In contrast to other studies in ponderosa pine forests, Taylor (1935) observed the heaviest porcupine damage in dry, rocky sites where the ponderosa pines were slow-growing, small, and often had irregular growth forms. This observation may be explained by two other factors not related to the nutritive content of phloem per se: 1) the stunted trees were more heavily infested with dwarf-mistletoe (*Arceuthobium spp.*) than more vigorous trees (Taylor 1935); 2) porcupines appear to have higher population densities near rocky ridges, possibly because they find suitable den-sites in such locations.

Dwarf-mistletoe appears to be a favorite food source for porcupines. Stomach content analyses done by Taylor (1935) showed that dwarf-mistletoe was the principal food source for all porcupines (n =57) during September, October and November, and some individuals fed exclusively upon it throughout the winter. In some instances, porcupines have even been observed to remove the dwarf-mistletoe foliage without gnawing on the bark (Taylor 1935). Preference studies with captive porcupines have concluded that porcupines prefer dwarf-mistletoe over needles and phloem (Taylor 1935).

In eastern Oregon, Smith (1975) reported that most targeted Douglas fir trees were infected with dwarf-mistletoe. Damage was most extensive on infected branches. Smith found no correlation between dwarf-mistletoe and porcupine feeding, as Taylor (1935) had observed in Arizona. However, Lawrence (1957) claimed that infected ponderosa pine trees in eastern Oregon were preferentially fed upon by porcupines.

Besides dwarf-mistletoe, porcupines also select trees infected with *Leptographium* fungi. This root fungus clogs a tree's tissues, resulting in retention of sugar in the upper bole. Porcupines prefer infected trees even before there is any visible sign of infection (Spencer 1964). For unexplained reasons, porcupines have also been reported to preferentially feed upon lodgepole pines infected with Comandra blister rust (*Cronartium comandras*) (Mielke 1957 *in* Storm 1962).

Taylor's (1935) observation that target trees were growing near den-sites was also reported by others (Spencer 1964; Storm 1962). Other physical and geographical factors which may influence feeding patterns of porcupines are distance to water (Storm 1962; Speer and Dilworth 1978), proximity to summer feeding areas (Harder 1980; Van Deusen and Myers 1962), and canopy density (Taylor 1935; Curtis and Wilson 1953; Storm 1962; Smith 1979, 1982). These physical and geographical attributes may or may not be related to genetically-determined traits, although a tree's ability to survive in certain microsites may be influenced by genetic factors.

There is evidence that porcupines can consistently differentiate among phenotypes. In a study of ponderosa pine plantations in Washington and Oregon, porcupines showed a significant and repeated preference for trees from specific seed sources. The same preferences were maintained over a 32-year period and in two plantations occupying significantly different habitat types. These preferences were radically different from those of rabbits and deer, which were more similar to each other than to porcupines in their feeding patterns (Squillace and Silen 1962).

In summary, evidence for selective feeding by porcupines is scattered, and sometimes contradictory. Observations of porcupines and dwarf-mistletoe provide a glimpse of how complex the relationships among host tree, parasites, and herbivores can be. For example, it has been demonstrated that susceptibility of a tree to dwarf-mistletoe parasitism has a genetic component and that the presence of dwarf-mistletoe significantly reduces the fitness of a tree (Roth 1974). If a parasitized tree is unharmed when a porcupine consumes the dwarf-mistletoe, as has been reported (Taylor 1935), the tree's fitness may be increased. If, however, the porcupine also consumes tree tissues, as has also been observed (Lawrence 1957; Smith 1975), then the fitness of the tree may be reduced.

DIFFERENTIAL UTILIZATION OF PONDEROSA PINE PHLOEM BY ABERT'S SQUIRRELS AND PORCUPINES

As discussed above, Abert's squirrels (food specialists) and porcupines (food generalists) differ with respect to

Table 2. Differences between target and non-target trees fed upon by Abert's squirrels and by porcupines. All features are $\bar{X} \pm$ S.E. Sample sizes: for squirrels, N = 23 paired comparisons for phloem characters, and 20 paired comparisons for xylem characters, except N = 60 for xylem oleoresin flowrate values; for porcupines, N = 20 paired comparisons for phloem characters, and N = 17 paired comparisons for xylem characters. All squirrel-related tests involved trees at one site, within a relatively small area. Porcupine-related tests were done with trees at several sites, distributed over a much larger area. Analyses varied with characters compared and included ANOVA and Mann-Whitney U-tests. Levels of significance are shown for each character.

	Dependent Species					
	Squirrel			Porcupine		
Character	Target trees	Non-target trees	Signif.	Target trees	Non-target trees	Signif.
PHLOEM:						
Total nonstructural carbohydrates (%)	6.5 ± 0.4	4.7 ± 0.5	<.025	8.5 ± 0.5	8.6 ± 0.4	N.S.
Zn (ppm)	38.0 ± 1.8	38.8 ± 1.5	N.S.	35.4 ± 1.1	37.2 ± 1.15	N.S.
Ti (ppm)	1.6 ± 0.1	1.8 ± 0.2	N.S.	1.8 ± 0.2	2.3 ± 0.2	0.042
Na (ppm)	18.0 ± 2.5	9.9 ± 1.5	<0.01	5.9 ± 2.9	5.8 ± 2.7	N.S.
Si (ppm)	40.2 ± 4.3	47.1 ± 4.7	0.07	91.6 ± 8.2	111.5 ± 9.6	0.036
Hg (ppm)	0.04 ± 0.02	0.12 ± 0.03	<0.05	0.02 ± 0.01	0.03 ± 0.10	N.S.
Mg (ppm)	968.2 ± 40.2	973.9 ± 57.7	N.S.	1348.7 ± 47.0	1513.4 ± 161.4	0.011
XYLEM OLEORESIN:						
α-pinene (%)	9.3 ± 2.3	7.4 ± 1.2	N.S.	7.5 ± 2.2	7.0 ± 0.9	N.S.
β-pinene (%)	16.7 ± 1.7	22.6 ± 2.1	<0.05	22.5 ± 2.7	23.1 ± 2.0	N.S.
myrcene (%)	7.3 ± 1.2	7.2 ± 0.8	N.S.	7.5 ± 0.8	6.6 ± 0.7	N.S.
limonene (%)	2.1 ± 0.8	3.6 ± 0.9	<0.05	1.5 ± 0.4	3.5 ± 0.7	N.S.
β-phellandrene (%)	0.5 ± 0.1	0.8 ± 0.1	<0.01	0.9 ± 0.1	0.8 ± 0.1	N.S.
r-terpinene (%)	0.14 ± 0.03	0.19 ± 0.03	<0.05	0.2 ± 0.04	0.2 ± 0.02	N.S.
Flowrate (ml/24h)	2.0 ± 0.4	5.9 ± 0.6	<0.001	4.5 ± 0.9	5.9 ± 0.6	N.S.

observed patterns of host tree utilization. Below we present empirical evidence of differential host tree utilization by these two species in Arizona and Colorado.

In the Pearson Natural Area northwest of Flagstaff, Arizona, over 3300 trees were tagged and damage by several dependent species was noted periodically over a 50-year period by U.S. Forest Service personnel (Avery et al. 1976). Preliminary tabulations show evidence of different trees being selected by porcupines and squirrels. A tree was recorded as damaged if it was attacked by one of the dependent species at any time during the 50-year period. Abert's squirrels and porcupines usually fed on different trees. There were no consistent size differences between trees upon which the two species fed. Of 655 trees attacked by either animal species, only 18 were fed upon by both. If utilization by the animals were completely random, 27 trees would be expected to show damage by both. The difference is not statistically significant, however the pattern observed and our data from the Colorado Front Range suggest that 1) the animals rarely select the same target trees, and 2) those attacked by squirrels and those attacked by porcupines have different characteristics.

In the Colorado Front Range, one of us (M.A.S.) is completing six years of work on Abert's squirrel-ponderosa pine interrelationships. Porcupine feeding patterns are being investigated by S.A.H. Although the focus and scope of our work have differed, the measurement of a variety of characters was common to both our investigations, and therefore permits comparison of tree characteristics associated with feeding patterns of the two mammals. Within each study, trees which showed evidence of recent feeding were designated as target trees. For each target tree, a corresponding non-target tree was designated on the basis of a list of criteria, including size, vigor, proximity to target tree, solar exposure, slope, etc. Comparisons were made between these pairs of target and non-target trees. A partial comparison between trees fed upon by squirrels and porcupines appears in table 2.

Abert's squirrels at three Front Range sites use only a small percentage of trees (<10%) in stands which support them. As discussed in more detail below, target tree choice is apparently mediated by a number of tree characteristics, including xylem oleoresin flowrate and monoterpene composition, as well as nonstructural carbohydrate and

mineral content of the phloem (Snyder in prep.). Monoterpene composition of the oleoresin is known to have a strong genetic basis (Smith 1977), hence the squirrels appear to be feeding, at least in part, in response to genetically-determined tree characteristics. Furthermore, trees which are utilized as sources of phloem show consistently lower reproductive output than corresponding non-target trees (Snyder in prep.).

Porcupines may also act as selective agents when they preferentially feed upon trees which have high or low levels of specific elements. Although levels of elements in plants are known to be affected by soil composition, many plants have been shown to have genetically-based variation in their propensity to take up and store a variety of elements (Antonovics et al.). The negative effects of phloem-feeding upon host trees have been documented by Lawrence (1957) and others (Taylor 1935; Storm and Halverson 1967; Smith 1975).

Although feeding by Abert's squirrels was significantly affected by qualitative and quantitative oleoresin characteristics, no such pattern was seen for porcupines (table 2). Phloem of trees utilized by Abert's squirrels had significantly higher concentrations of nonstructural carbohydrates and sodium, and lower concentrations of mercury, than that of corresponding non-target trees. Trees utilized by porcupines, however, had lower concentrations of silicon, titanium and magnesium than corresponding non-target trees.

We conclude from evidence presented above that:

1. Abert's squirrels and porcupines can act as agents of natural selection in ponderosa pine forests.
2. Because of their differential feeding patterns, Abert's squirrels and porcupines can generate diversifying selection within stands.

MANAGEMENT IMPLICATIONS

Management strategies developed for ponderosa pine stands and the dependent species which inhabit them will vary with management objectives. For example, Abert's squirrels will not likely be tolerated in seed orchards, nor porcupines in young plantations. However, these are specialized circumstances over most of the species' range. Most ponderosa pine forests are too extensive, and management objectives too complex, to lead to specific recommendations relevant to all forest conditions. We suggest, however, that certain broadly-implemented strategies of the past may not be appropriate to multiple-use management goals, in light of what we are learning about the interplay between ecology and genetics in natural stands.

In 1950, a typical response to the presence of porcupines was, "effective control can be obtained by poisoning and shooting as complementary measures" (Pearson 1950). These recommendations, along with trapping, have continued to be advocated over the decades both for tree squirrels (e.g. Pearson 1950; Evans 1988) and porcupines (e.g. Knowlton and Bruce 1954; Lawrence 1957; Hoover 1971; Smith 1975; Evans 1986, 1988), despite the fact that these measures have often been ineffective, and/or harmful to other forest denizens (e.g. Cooke and Hamilton 1957; Evans 1988).

It has become evident, in fact, that unusually large "pest" populations often result from human intervention in natural communities. For example, in many forests, high porcupine population densities have corresponded with the over-trapping of the porcupine's primary natural predator, the fisher (*Martes pennanti*) (Stone 1952; Cook and Hamilton Jr. 1957; Smith 1975; Earle and Kramm 1981). Another porcupine predator is the mountain lion, *Felis concolor*, (Maser and Rohweder 1983) and it has also been decimated in many regions. Other human activities which may increase forest pest populations include fire suppression, logging, thinning, and establishment of plantations (Stone 1952; Cook and Hamilton Jr. 1957; Lawrence 1957; Sullivan 1986).

Because dependent species attack specific trees often on the basis of host phenotype, the impact of a given dependent species upon an entire stand is likely to be mitigated by maintaining genetically-variable forests. Maintaining genetic variability may be accomplished, in part, by maintaining forests that are reasonably similar in their complexity to those which existed prior to the arrival of Euro-Americans. In this context, the feeding activities of porcupines and Abert's squirrels should not be viewed as detrimental. This is not to say that squirrels and porcupines are "good" for the trees they damage. However, ecologically complex environments are known to maintain genetic variability within populations (Hedrick et al. 1976). For this reason, we suggest that management plans for existing ponderosa pine forests take into account the importance of maintaining ecological complexity.

In the context of forest regeneration, we already know that seed sources must originate from locations as close as possible to the site to be regenerated, because of the finely-tuned adaptations to local physical conditions known for ponderosa pine (Rehfeldt 1987; Linhart 1988). In addition, the possibility of diversifying selection by a variety of dependent species, as illustrated here and in Linhart (1989), suggests that seed sources must be as variable as possible, incorporating dozens, and if possible, a hundred or more seed parents in order to produce the large diversity of phenotypes needed to cope with the large diversity of dependent species feeding on ponderosa pine.

In the context of multiple-resource management, an additional comment seems relevant. Looking for sawlogs in the thick-branched, short trees of the Central and Southern Rocky Mountains and the southwestern U.S. makes little economic sense. It is more appropriate to recognize the value of these forests as important wilderness, camping, and recreation areas. The fact that we need to make reservations for camping in some of these forests is a clue to the importance of wild areas. From this perspective, maintaining (or allowing the continued existence of) reasonable populations of wildlife is important, even if some species feed on ponderosa pine. If we were successful in eliminating all animal species that sometimes damage trees, we might have trees that grow faster and produce more wood volume and/or seeds. But such an approach would clearly be inconsistent with multiple-use management goals.

In summary, we suggest that (1) the maintenance of genetic variability which results from diversifying selection is important to the overall health of forests which are managed for multiple uses; and (2) management strategies intended to minimize the effects of phloem-feeding by Abert's squirrels and porcupines (or other species affecting tree fitness) should recognize the potentially important role of these species in generating diversifying selection within stands.

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Problems of Maintaining a Viable Black Bear Population in a Fragmented Forest[1]

Cheryl M. Mollohan and Albert L. LeCount[2]

Abstract.--From 1980 through 1985 the population characteristics and habitat requirements of a black bear (Ursus americanus) population were studied in both fragmented and unfragmented ponderosa pine-mixed conifer forests in north-central Arizona. Fragmentation of habitat made it difficult for animals to move between remaining habitat, increased vulnerability in and between remaining habitat, and restricted the ingress of new animals to replace individuals being lost from the population. We concluded that the population in fragmented habitat was historically fragile because of its dependence on low quality habitat, and that this quality had been further reduced through natural resource management practices that increased fragmentation. Fragmentation threatened the viability of the population by contributing to increased exploitation of adult females without compensating cub or subadult survival needed to replace them. Due to these effects bears in fragmented ponderosa pine-mixed conifer forest must be more closely monitored than in continuous habitat to assure that the viability of these populations are not lost.

INTRODUCTION

Forests throughout the world are changing dramatically due to an ever increasing human population's demand for wood products. Total forest acreage is being reduced, naturally uneven aged forests are being converted to even-aged monoculture plantations, and remaining natural forests are being fragmented into progressively smaller patches (Harris 1980).

Forest fragmentation has caused concern about its effect on wildlife (U.S. Dept. State 1982) because as timber stands become more isolated they take on characteristics of islands (Harris 1984). Movements of resident animals between these islands becomes more difficult and requires more energy; reduced ingress and egress of new species members reduces genetic diversity and limits recolonization; and small populations become subject to over-exploitation due to increased vulnerability in and between islands of suitable habitat (Harris 1984).

These concerns have prompted wildlife biologists to examine the effects of forest fragmentation on various species of wildlife (Harris 1984, Meslow et al. 1981, Schoen et al. 1981, Robbins 1979, Thomas 1979). Bear biologist have also been examining how black bears use forests, and a great deal of information can be found on habitat use (Tracy et al. 1982)). Little information, however, is available on the effects of forest fragmentation on bears. Fragmentation can result in direct habitat loss, but also has the potential to influence movements, dispersal, survival, and the ability of a population to remain viable.

From 1980-1985 we worked on a black bear habitat and population study on a highly fragmented forest in north-central Arizona. Some of the results of this project have been reported in Mollohan et al. (1989), Mollohan (1987), and LeCount

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(1987a, 1987b). However, while working on this project we were also able to observe and document some of the effects of forest fragmentation on bears. This paper describes these effects, how they relate to the problems of maintaining viable populations, and discusses problems that bear and habitat managers will face if their own forested bear habitat becomes fragmented.

This study would not have been possible without the help and enthusiasm of many volunteers and students that helped in data collection and summary. Technical assistance was provided by W. Carrel, R. Benda, and J. Wegge. This study was conducted under Fed. Aid in Wildl. Restor. Proj. W-78-R, Ariz. Game and Fish Department.

STUDY AREA

The 180 sq. mi. Leonard Canyon study area straddled the Mogollon Rim in north-central Arizona (Fig. 1). Elevations range from 4,900 to 7,800 ft. Precipitation averages 18.6 in., much of which falls as snow in the winter months. Temperature extremes usually range from just below 0F to about 93F (Sellers and Hill 1974).

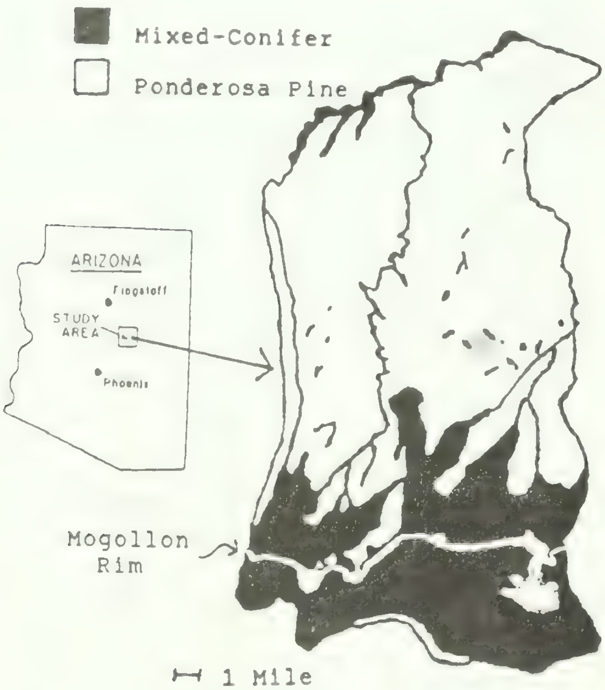

Figure 1.--Distribution of mixed-conifer and ponderosa pine vegetation on the Leonard Canyon study area, Arizona.

The Mogollon Rim is a large geologic escarpment running east to west across north-central Arizona. Topography on the 150 sq. mi. portion of the study area north of the Rim is comprised of relatively flat plateaus separated by deep canyons, and on the 30 sq. mi. area south of the Rim is made up of many steep small canyons and ridges.

This topography influenced the development of vegetation. South of the Rim more uniform soils and moisture created sites for the development of extensive stands of mixed-conifer forest. North of the Rim mixed-conifer was confined primarily to the moist canyons, and at the highest elevations along the Rim. Intervening dry ridges were covered by open ponderosa pine forest. This development fragmented the mixed-conifer vegetation into long "stringer" or "island" type blocks of habitat, with a thin band of contiguous mixed conifer near the Rim (Fig. 1).

In the late 1930's this natural fragmentation was compounded by logging. Accessible, highly economical ponderosa pine areas along ridgetops were the first to be cut, but since then almost all of the accessible ponderosa pine and mixed-conifer has been logged. By 1985 a road density of 1.9 miles of road per section had been established, and only 11% of all sections on the northern portion of the study area remained roadless (LeCount 1987b). In 1982 steep slope logging also began in the mixed conifer canyon areas. From 1982 through the conclusion of this study 15 sections on the study area had been cable logged. South of the Rim, since ponderosa pine was not abundant, little logging occurred through 1985. As a result the bear habitat remained intact and a road density of only 1.3 miles per section was established. Thirty-four percent of all sections remained completely roadless.

METHODS

Bears were captured using Aldrich foot snares and immobilized with Sernylan (phencyclidine hydrochloride). A first premolar was extracted from each captured animal and age was determined by the cementum annuli technique (Stoneberg and Jonkel 1966). Each captured bear was tagged for subsequent identification and radio transmitter collars were attached to 26 animals exceeding 1 year of age. To determine movements and home range sizes 2,120 locations were made by radio-tracking from the ground and aircraft. Home range sizes were determined by using a minimum size polygon with the area

calculated from the sum of interior triangles method (Southwood 1966).

To determine population densities north and south of the Rim, bears were divided into three age classes: cubs (< 1 year), subadults (1-3 years), and adults (> 3 years). Population size was estimated using the Leslie method (Ricker 1975) for only the adult segment of the population. The number of subadults was estimated by computing the average percent subadults captured. Details of calculations of population estimates can be found in LeCount (1987b).

Mortality of bears greater than 1 year of age was determined from radio-tracking and harvest data. Hunting seasons occurred each year on the study area but season length and techniques varied from year to year. From 1980-1982 bears could be taken from 1 September to 30 November with the use of dogs, baiting, or non-aided hunting. From 1983-1985 the season was shortened to 2 weeks in early September and the use of baits was made illegal. In all years each hunter was allowed one bear per calender year, and was required to notify the Arizona Game and Fish Department within ten days after making a kill.

Mortality of bears less than 1 year of age was determined by radio-collaring cubs in winter dens with a mortality sensing, break-away radio-collar. Cubs were then intensively radio-tracked until they died or the animals lost their radio collars. Dens of all females accompanied by marked cubs were examined the following winter to determine cub survival through the first year of life (LeCount 1987a).

Habitat quantity was determined by using U. S. Forest Service vegetation maps to identify acres of various vegetation types on the study area. Bear use sites were classified by vegetation type or association based on Brown et al. (1979). The chi-square "goodness of fit" test (Zar 1974) was used to detect significant differences between the availability and observed use of vegetation types, site characteristics, and slopes. Preference or avoidance of each individual habitat component by collared bears was determined by applying a modified z statistic (Marcum and Laftsgaarden 1980).

Habitat quality was determined by identifying bear use microsites through intensive ground radio-tracking of radio-collared animals. After the bear was located it was left undisturbed until it departed the area. The site was then gridded for sign to verify the radio location. If fresh feeding or bedding sign was found the site was sampled. Aspect, percent slope, logging history, topographic location and distance to nearest water were recorded. Vegetative cover and species composition were determined using a 100 foot line intercept transect. Vertical cover was determined at 3 height levels (0-1 ft., 1-6 ft., and > 6 ft.). Horizontal cover was measured using a cloth silhouette of an average size Arizona black bear and measuring the distance at which 90% of this silhouette was hidden from view. A 1/100 acre circular plot was used to obtain densities of trees and shrubs by species. The number of bear forage plants was recorded at each site, and actual food availability was also recorded by phenology ratings. Further details of habitat data analyses can be found in Mollohan (1987).

RESULTS

The Habitat

Six major vegetation types occurred on the study area; mixed-conifer, ponderosa pine, ponderosa pine-alligator juniper, maple-white fir, and grass meadow. North of the Rim ponderosa pine was the most abundant vegetation type covering 62% of the area, followed by mixed-conifer which occupied 23%, and ponderosa pine-alligator juniper with 9%. South of the Rim 96.9% of the area was covered by mixed-conifer. In this area, however, the mixed-conifer overstory contained an understory of manzanita (<u>Arctostaphylus pringleii</u>), emory, turbinella, and Gambel oak (<u>Quercus emoryi, Q. turbinella, Q. Gambelii</u>) and New Mexico locust (<u>Robinia neomexicanus</u>). Such a diverse understory did not occur in mixed-conifer areas north of the Rim.

Locations of radio-collared females yielded 182 bear use sites. Eighty-eight of these locations were classified as feeding sites and 57 as bedding sites. Thirty-seven contained both bedding and feeding sign. Ninety-six of all sites were occupied by females with cubs and 86 were without cubs.

Analyses of use versus availability of habitat types reveled that bears throughout the study area selected primarily for mixed- conifer, and maple areas, and against ponderosa pine. This was especially obvious north of the Rim where these 2 types made up only 23% of the vegetation but received 75% of the use (Table 1).

Total number of food species was greater south of the Rim than north due to the increased variety of mast and berry

Table 1. -- Availability of habitat types versus percent use ( ) by portions of the Leonard Canyon, Arizona, study area, and home ranges of 2 adult female bears.

	Study Area North of Rim	Study Area South of Rim	Rose (#83)	Horton Female (#71)
Mixed-Conifer	22.6(62.7)	97.0(100.0)	22.2(64.9)	100.0(100.0)
Ponderosa Pine	62.1(10.6)	3.0(0)	68.2(16.2)	0.0(0)
Ponderosa-Alligator Juniper/Pinyon Juniper	8.8(11.9)	0.0(0)	1.7(0)	0.0(0)
Riparian	1.2(2.8)	0.0(0)	0.7(0)	0.0(0)
Grassland or Meadow	0.8(0)	0.0(0)	0.7(0)	0.0(0)
Maple	1.1(11.9)	0.0(0)	1.8(18.9)	0.0(0)
Home Range Sq. Mi.			61.6	16.1

producers in the understory, but at the time bears were found at individual feeding sites the number of food species available in any vegetation type was only 2. Cover, however, did vary between vegetation types. In mixed-conifer sites, cover between 1 and 6 ft. in height averaged 34% and horizontal visibility was 53.0 feet, and in maple 62% and 40.6 feet respectively. In contrast, ponderosa pine sites provided only 8% cover between 1 and 6 ft in height, and horizontal visibility was 93.5 feet (Mollohan et al. 1989). Bears also selected for topographical features. The study area was made up of 55% ridgetops, but only 13% of the use occurred there. In general bears selected against slopes <20% and for slopes of 20-60% (Mollohan 1987).

It appeared that bears on the study area selected habitat types on the basis of cover first and food second. Based on use of habitat types it appeared that the 62% of the area covered by ponderosa pine north of the Rim was largely unusable because of lack of cover both vegetatively and topographically. This forced bears to actually live in only about 35% of the land area. South of the Rim 97% of the land mass was usable and the habitat was not fragmented into "stringers" and " islands" as it was to the north.

Comparison of home range sizes showed that bears in fragmented habitat north of the Rim used larger areas than bears in unfragmented areas. Home range sizes for adult females in fragmented and unfragmented habitat averaged 40.0 and 15.5 sq. mi respectively. Adult males in both areas had larger home ranges than adult females, but like females they were considerably larger in fragmented habitat. In unfragmented areas males used an average of 75.0 sq. mi. but in fragmented habitat home ranges averaged 235.0 sq. mi.

Bears in unfragmented habitat also did not make long movements within their home ranges. Their net weekly movements averaged less than 0.9 miles. Movements out of normal home ranges were also rare, and if they did occur these movements rarely exceeded 1 mile in length and all animals returned within a few days. Net weekly movements in fragmented habitat, however, averaged 2.4 miles, and all animals moved more frequently within their home range. Movements outside normal home ranges were also more frequent. Distances moved averaged approximately 10 miles, and most animals normally spent several weeks off the study area.

The Population

Over the 5 years of study 73 individual bears (45 Males, 28 Females) were captured 106 times. Forty of these animals were captured north of the Rim (29 Males, 11 Females), and 33 south of the Rim (16 Males, 17 Females). Estimated population size was 23 animals, or 1 bear/6.5 sq. mi. north of the Rim, and 21 bears, or 1 bear/1.4 sq. mi. south of the Rim. Mean age of males north of the Rim was 3.4 years, while females averaged 5.7.

South of the Rim mean ages were 5.3 and 5.6 years respectively (LeCount 1987b).

Sex ratios of adult bears did not vary significantly from the expected 50:50 ratio on either portion of the study area. However, cub and subadult ratios north of the Rim were both significantly weighted toward males ($P<0.05$) (Table 2). The reason for the preponderance of male cubs is not known, but it appeared that the high number of subadult males resulted from an ingress of young males into an area where heavy harvest was removing many bears.

The majority of females throughout the study area had a minimum breeding age of 3.5 years. Observed mean litter size in 28 litters was 1.8 cubs. No difference in mean litter size was observed on either portion of the study area (LeCount 1987b).

Of 116 bears captured or tagged in winter dens during this study 45 (39%) died; 17 cubs, 13 subadults, 15 adults (Table 3). In addition 23 untagged bears were also taken from the study area by hunters; 2 male cubs, 8 male subadults, 7 adults (3 Males, 4 Females), and 6 bears (3 Males, 3 Females) of unknown age.

Most of the mortality throughout the study area was due to hunting (Table 3). Forty-three percent of all tagged subadults died with the majority (85%) of the loss being due to hunting. Adult mortality during the study was 35% but the highest mortality occurred north of the Rim where 55% of all tagged adults were killed. The primary cause of death north of the Rim was due to hunting, which accounted for 82% of the total mortality.

Table 2.--Sex ratios of adult, subadult, and cub black bears on the Leonard Canyon Study Area, Arizona.

	Above Rim		Below Rim	
Age Class	%Male	%Female	%Male	%Female
Adults[1]	55(11)[4]	45(9)	48(11)	52(12)
Subadults[2]	90(18)[5]	10(2)	50(5)	50(5)
Cubs[3]	72(13)[5]	28(5)	48(10)	52(11)

[1]Adults = >3 years.
[2]Subadults = >1 to 3 years.
[3]Cubs = 0 to 1 year.
[4]Number of individuals.
[5]Significant variation from 50:50 at the .05 level.

Hunting also accounted for most of the mortality below the Rim but only 13% of the total tagged adults were shot (Table 3).

DISCUSSION

Forest fragmentation has caused concern among biologist working with various species of wildlife because as fragmentation progresses remaining timber stands become isolated and begin to take on the characteristics of island ecosystems. These islands of habitat have the potential to effect wildlife by making it more difficult for individuals to move between remaining habitat, by increasing vulnerability in and between remaining habitat, and by restricting the ingress of new animals to replace individuals being lost. It appears that these concerns are all valid for bears as their habitat becomes fragmented.

Habitat Use

Forest fragmentation appeared to effect how bears used their habitat in three ways; the area they needed to make a living, their movements between usable habitat within their normal home range, and their movements to important seasonal use areas outside their normal home range.

Distribution and quantity of food has been identified as being very important in influencing black bear movements and home range sizes (Graber 1982, Amstrup and Beecham 1976, Jonkel and Cowan 1971). Lindzey and Meslow (1977), however, also identified the importance of cover to bears, and showed that the availability and juxtaposition of both food and cover contributed to overall habitat richness.

In this study cover also appeared to be important. Mixed- conifer was found to be very important to bears throughout the study area. What appeared to make this vegetation type usable was not the foods found in it, but the amount of cover it provided a bear. This vegetation type, like the unused ponderosa pine type, provided a bear an average of 2 food items while it was at the site, but horizontal cover between 1 and 6 ft. in height in this vegetation type averaged 50 feet. In ponderosa pine habitat horizontal cover averaged 94 ft. Bears were rarely located using or traveling through open ponderosa pine areas even if food was available. It is important to remember that bears were probably selecting the mixed-conifer type because of the structure of the habitat, not the species composition. Bears did not use areas of flat, open, mixed-conifer

Table 3. -- Causes of mortality of tagged cubs[1], subadults[2], and adults[3], on the Leonard Canyon Study Area, Arizona.

	North of Rim			South of Rim			Both Areas		
	Cubs	S/adults	Adults	Cubs	S/adults	Adults	Cubs	S/adults	Adults
Total Tagged	21	20	20	22	10	23	43	30	43
Total Dying	8	8	11	9	5	4	17	13	15
Percent Dying	38	40	55	41	50	17	40	43	35
Cause of Mortality									
Hunting	1	7	9	0	4	3	1	11	12
Bear Predation	2	0	0	2	1	0	4	1	0
Other Predation	0	0	0	2	0	0	2	0	0
Road Kill	0	1	0	0	0	0	0	1	0
Disease	1	0	0	0	0	0	1	0	0
Capture	0	0	1	0	0	0	0	0	1
Unknown	4	0	1	5	0	1	9	0	2

[1]Cubs = 0 to 1 year.
[2]Subadults = >1 to 3 years.
[3]Adults = >3 years.

that did not provide adequate cover, and in the few instances that ponderosa pine was used it always occurred on slopes >20%.

South of the Rim usable mixed-conifer habitat covered 97% of the entire area, and occurred homogeneously throughout the area. North of the Rim mixed-conifer habitat made up only 23% of the total area, and was broken up into many small blocks separated by stands of ponderosa pine. As a result bears in these fragmented areas appeared to have to use larger areas to meet their needs as evidenced by home ranges of animals in fragmented habitat averaging approximately 5 times larger than home ranges in unfragmented habitat. However, these bears did not actually have more resources available to them in these larger home ranges. If the 62% unusable ponderosa pine habitat is removed from the home range calculations the actual habitat available to males and females in fragmented habitat averaged 87.2 and 14.8 sq. mi. respectively. These home range sizes are not significantly different ($P<.05$) from the 75.0 and 15.5 sq. mi. used by bears in unfragmented habitat.

Movements within home ranges also appeared to be influenced by fragmented habitat. Bears in fragmented areas were found to move longer distances and more frequently than those in unfragmented habitat. Two females exemplify these movements.

Female #83 (Rose), a 7.5 year old, had a 61.6 sq. mi. home range of which 26% was usable habitat (Table 1). This home range was split into many small mixed-conifer islands separated by large blocks of unusable habitat. To use this habitat Rose had to move between these small islands usually by way of connective drainages. Weekly locations made during 1982 typify these movements. During this time her weekly net movements averaged 2.3 miles per week (Fig. 2).

In contrast, bear #71 (Horton Female), a 5.5 year old female living south of the Rim had a home range of 16.1 sq. mi. that contained 100% usable unfragmented habitat (Table 1). In 1982 Horton Female moved regularly throughout her home range, but her average weekly net movements were only 0.5 miles per week (Fig. 3).

Forest fragmentation also appeared to effect bear movements to areas outside their normal home ranges. In regions with relatively homogeneous vegetation bears remain in the same areas all year and rarely make excursions outside their home ranges to find food (LeCount et al. 1984, Alt et al. 1977, Rogers 1977). Such behavior was typical of bears south of the Rim. In this area food supplies were more diverse and abundant than in areas to the north due to the variety of mast and berry producers found in the understory on this portion of the study area. In the course of 5 years of study only 4 of the 10 adult female bears inhabiting this area were observed leaving their normal home ranges, and when they did these movements normally did not exceed 1 mile in length and the animal was not out of its normal home range more than a few days.

Movements of bears to areas outside their normal home ranges in the fragmented northern portion of the study area, however, were more typical of seasonal movements observed in other areas where food availability fluctuated during the year (Graber 1982, Amstrup and Beecham 1976). This portion of the study area contained abundant grass and forbs until mid summer when this material matured and dried, but contained only one soft and one hard mast producer [raspberry (Rubus strigosus), Gambel oak]. Consequently, due to the lack of diversity of late summer and fall food producers, food availability in some years was seriously limited or non existent. During the course of this study all radio-collared bears north of the Rim made excursions to food resources south of the Rim. Fragmentation appeared to effect these movements.

Adult females began movements in late July and continued through August. The longest movement recorded was 21 miles but most were 10 miles or less. Major canyons and sidecanyons that provided both vegetative and topographic cover were used as travelways. Females moved south through these corridors and utilized seasonal areas directly south of their normal use areas. No east west movement was noted. Most females remained off the study area until September, but some did not return until shortly before denning time in November. Returns were made through the same travel corridors used to move off the study area.

Adult males also made late July and August excursions from their normal use areas but these movements were made more often and were longer than those of females. Males commonly moved 30 to 40 miles south of their normal use areas. Most used the same north-south canyon travelways used by females but several

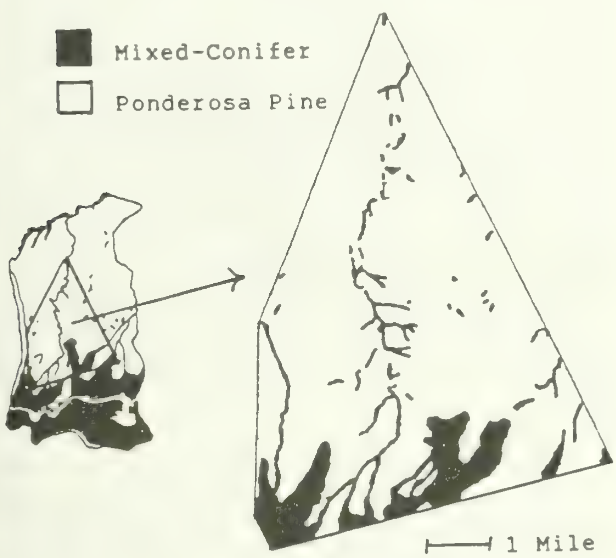

Figure 2.--Distribution of mixed-conifer and ponderosa pine vegetation in bear #83 (Rose's), 62 sq. mi. home range.

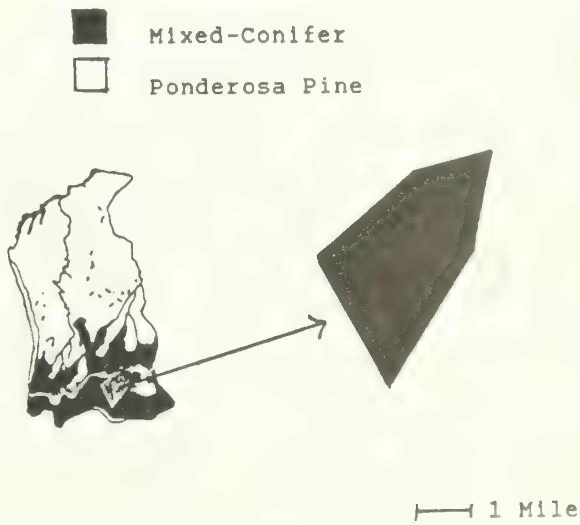

Figure 3.--Distribution of mixed-conifer and ponderosa pine vegetation in bear #71 (Horton Female's), 16 sq. mi. home range.

traveled east and west through small islands of fragmented habitat. Like females, males returned to their normal use areas on the study area to den by the same travel corridors.

Population Regulation

Habitat quality appears to be the ultimate factor in controlling black bear numbers but other factors such as nutrition, cub survival, subadult dispersal, habitat deterioration, and hunting can all be proximate regulating mechanisms (Kolenosky 1986, Hugie 1982, LeCount 1982, Young and Ruff 1982, Beecham 1980, Lindzey and Meslow 1977, Rogers 1977). In this study it appeared that increased vulnerability of adults and lack of replacement of individuals lost were the most important. Both of these problems were effected by forest fragmentation.

As forests become fragmented bears become more vulnerable to hunting because they are concentrated into smaller areas, and, if this fragmentation is created by logging the resulting road system also provides increased hunter access into bear habitat. The northern portion of the study area evolved in a naturally fragmented condition but intensive logging, especially during the 1970's and 80's compounded the problem.

This intensive logging benefited hunters. Road access was greatly increased, and bears were forced to either spend more time in smaller islands of habitat, or make more frequent moves between islands. The results of this increased fragmentation were that hunters became much more efficient at killing bears.

Of 61 bears marked north of the Rim, 17 (28%) were killed by hunters. This is in contrast to south of the Rim where only 7 of 55 (13%) were taken (Table 3). Adult females were particularly impacted in fragmented habitat. Of 9 adult females tagged during the study only 2 remained alive at the end. Hunters accounted for 5 of 7 (71%) of the mortalities. In unfragmented habitat only 1 of 12 (17%) tagged adult females were taken by hunters (Table 3.). Both of these harvest levels are much higher than on an unfragmented central Arizona study area where only 1 of 19 (5%) tagged females was harvested in an area where road densities were 0.2 miles per section (Lecount 1982). Based on our observations hunter density was similar on all three areas.

This high loss of adult females in fragmented habitat reduced the overall reproductive capacity of the population. The high harvest rate, combined with natural mortality of adult females, resulted in a 78% reduction in the number of breeding females in the population. This loss of females reduced the maximum cub production from an average of 9 cubs per year to 2. This cub production might have be adequate to maintain the population if all cubs survived to adulthood but unfortunately this was not the case.

Of 21 cubs tagged on the fragmented portion of the study area 8 (38%) died (Table 3). This cub mortality rate was not significantly different from that found in unfragmented habitat, and although higher than in other states (Alt 1982, Jonkel and Cowan 1971) appears to be typical for Arizona (LeCount 1984). Survival beyond the first year of life, however, was poorer in fragmented habitat. Of 20 tagged subadults 7 (35%) died. All were taken by hunters (Table 3). Subadult females, like their adult counterparts, were severely impacted by hunting. During the entire study only 2 subadult females were captured in the entire 150 sq. mi. area north of the Rim, and both of these were killed before they reached breeding age. This is in contrast to the adjacent unfragmented habitat south of the Rim where 5 subadult females were captured and only 1 was killed.

This low cub and subadult survival, especially in the female segment of the population, appeared to be making it very difficult for the population in fragmented habitat to remain viable. A number of adult females were being taken each year but during the course of the study not one new female was known to be added to the population. This alone would be enough to restrict the viability of the population. However, this problem is compounded by the fact that subadult females rarely disperse from the area they were born in. While young males leave their area of birth after family breakup subadult females normally remain in their mother's home range until they become adults. As adults they often occupy adjacent home ranges to their mothers (Rogers 1977). Therefore, the only way to replace females being killed is for them to be produced by the adult females surviving on the study area.

CONCLUSION

Forest fragmentation tends to create small "islands" of usable habitat in a "sea" of unusable habitat. Movements of resident animals between these island becomes more difficult, ingress and egress of new species members is limited, small populations become subject to over-

exploitation, and in some cases extirpation occurs (Harris 1984). This appears to be what is happening to one of our northern Arizona bear populations.

Analyses of habitat data showed that bears were primarily limited to mixed-conifer, vegetation associations because of the lack of cover and topography in other vegetation types. Virtually all of the habitat south of the Rim was made up of these associations and was usable to bears on a year round basis because it was not fragmented or isolated from other bear habitat. This habitat supported a density of 1 bear/1.4 sq. mi.

Terrain in this area was also steep and road densities low. As a result hunter access was poor, and during the 5 years of study hunters killed only 4 of 10 (40%) subadults tagged, and 3 of 23(13%) tagged adults. Of these 7 individuals only 2 (1 adult, 1 subadult) were females. As a result of this light hunting pressure the age structure of the population was characteristic of a lightly hunted population with 70% of the bears being breeding age animals (LeCount 1982, Beecham 1980). This high number of breeding age animals appeared to allow for adequate reproduction to replace animals lost to both natural causes and to hunting, and unless harvest levels increase this population should remain stable.

North of the Rim the situation was much different. Usable habitat in this area was fragmented into small "islands" and "stringers" separated by large expanses of unusable ponderosa pine. Only 28% of the entire 150 sq. mi. area appeared to be usable for bears. This vast amount of unusable habitat in each animals home range caused home ranges sizes to be an average of 5 times greater than home range sizes for bears in unfragmented habitat, and as a result the population density averaged only 1 bear/6.5 sq. mi.

Terrain north of the Rim was relatively flat and had abundant roads. Good road access, coupled with fragmented habitat which limited bears to certain areas within their home ranges, or caused them to move through areas where they were more vulnerable, resulted in heavy hunter harvest. During the 5 years of study hunters harvested 7 of 20 (35%) tagged subadults and 9 of 20 (45%) adults. This harvest rate of adults and subadults is higher than other areas considered heavily hunted, and the 50% subadults found in the population is indicative of a highly exploited population (Kolenosky 1986, Young and Ruff 1982, Beecham 1980).

Even more important than the effect of heavy hunting on the population as a whole, however, was its effect on the female segment of the population. During the 5 years of study only 2 females died from non-hunting causes but 4 untagged and 5 of 9 tagged breeding age females where shot. During this same time period capture data, and monitoring of tagged subadult females, indicated that no new breeding females were added to the population. Undoubtedly all breeding females on the study area were not captured, but the frequency at which tagged females were recaptured indicated that this number had to be low. Therefore, the continued presence of breeding age females in fragmented habitat appeared to be seriously threatened. The 2 remaining females were growing older, and if not killed by hunters would eventually die of "old age." No new breeding age females were being added to the population because young females seldom disperse and a high percentage of the few female cubs that were being born on the area were being killed before they reached breeding age.

This naturally fragmented habitat has never, and will never be capable of supporting high bear densities, and its potential has been further limited by logging and related land use activities. As a result even if this population is rehabilitated over time it will never be able to withstand much pressure either from hunting or additional loss of habitat.

MANAGEMENT IMPLICATIONS

In fragmented habitats strong consideration must be given to preventing further fragmentation, and bear populations in such areas must be considered as very fragile and managed accordingly. Failure to consider both population and habitat management of bears in fragmented forests will inevitably lead to the decline, or even the loss, of the species in these areas.

Having an opportunity to observe bears in an area that contained both fragmented and unfragmented habitat allowed us to observe some of the changes that take place as fragmentation occurs. We believe strongly that habitat prone to fragmentation should be managed from the perspective of preventing, or halting fragmentation. Important management implications that bear and habitat managers should be aware of and consider, especially if land use practices are causing bear habitat in their area to become fragmented include:

First, as fragmentation occurs managers will have to increase their estimates of home range size and decrease estimates of population density. Fragmentation causes bears to travel over larger land areas to meet habitat needs which makes average home ranges larger, and loss of habitat due to removal of protective cover or food supplies in intervening areas decreases the total number of bears an area can support. This reduction in bear numbers will continue until unusable habitat regenerates to the point where it again adds to the total amount of usable habitat.

Second, fragmentation makes it difficult for bears to reach important seasonal food supplies. Travelways are eliminated and remaining travelways become increasingly important. As fragmentation occurs managers must make sure that isolated islands of habitat are kept to a minimum and that adequate travelways are provided between usable blocks of vegetation. If these steps are not taken bears will have greater difficulty moving to important food supplies and could become isolated from other usable habitat.

Third, forest fragmentation also increases bear vulnerability by concentrating bears and increasing hunter access. As an area become fragmented managers should anticipate that hunters will become more efficient and harvest will increase. To protect populations from overharvest managers must decrease their bear harvest by limiting more efficient hunting techniques or reducing the time hunters can be in the field. Also, since population densities will decrease as available habitat is reduced overall harvest will have to be lower than pre-fragmentation harvest to assure that overharvest does not occur.

Finally, bear populations in fragmented areas should be monitored very closely. Fragmentation not only has the potential to increase the number of bears harvested, but this increased mortality and the fragmentation itself can make it more difficult to replace animals being removed. If managers observe high numbers of females being harvested they can anticipate that reproductive potential will decline because fewer breeding age females will remain in the population. Also, as more bears are concentrated into remaining islands of habitat the potential for cubs to be found and killed by other bears, and for hunters to kill subadult females, is increased. This loss of replacement females, combined with the fact that subadult females rarely disperse, limits recruitment of new females into the population. Without new females being added a viable breeding population can be eliminated even though male bears still remain in the area.

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Effects of Timber Management Practices on Elk[1]

Richard L. Brown[2]

Elk were radio tracked to mid-day bedsites and standard overstory measurements that reflect thermal cover characteristics were taken. Sixty-four sites were located and measured in the ponderosa pine type. These have been described quantitatively and an attempt has been made to relate this information to the parameters currently used in the R03WILD modeling process.

INTRODUCTION

The accepted standard for optimum quality elk habitat calls for maintaining 60% of the total land mass in forage areas and 40% in cover areas (Black et al. 1976; and Thomas et al. 1979). Forage areas are defined as those that do not qualify as cover areas. Cover is divided into two types, hiding and thermal. Hiding cover provides an escape or security function and is defined as vegetation that will hide 90% of a standing adult elk at 200 feet or less (Thomas et al. 1979). Thermal cover protects from incoming solar radiation during warm periods and reduces the animals own radiation heat loss during cold periods. The 40/60 cover/forage ratio calls for 1/2 of the 40% to exist in the form of hiding cover, 1/4 in thermal cover and the remaining 1/4 in either hiding or thermal, whichever is the more limited.

The accepted description of habitat that provides summer thermal cover is "any stand of coniferous trees 40 feet or more in height with an average canopy closure of 70%" (Thomas et al. 1979). This definition was developed in the mixed conifer forests of Washington and Oregon. A large majority of Arizona's elk in the western half of the states range, and a much smaller percentage of those in the eastern half, summer in ponderosa pine forests. Pure ponderosa pine stands greater than 40 feet in height, rarely achieve the required 70% canopy closure. This suggests that a significant portion of Arizona's elk are using a totally different tree stand structure for this purpose. Additionally, a smaller percentage of Arizona's elk summer in Pinyon/Juniper woodland. The importance of adequate summer thermal cover is related to maintaining a high level of reproduction. (For a more detailed discussion and associated references see Brown 1987, pages 4 and 5).

The USDA Forest Service Region III is currently implementing new multi-resource stand management prescriptions for all National Forests within Arizona. In general, forests will be managed in 10,000 acre blocks (range 8,000-12,000) comprised of 10-100 acre even aged stands, except for the old growth component which will exist in 100-300 acre stands. The 40/60 cover/forage ratio will be used as a guideline. A series of multivariate habitat models will predict probable outcomes and track results of timber harvesting operations. The R03WILD habitat capability model for elk is based on tree structural stages as well as canopy closures. It is therefore necessary, not only to identify what elk are using and describe it, but also to relate this information to the structural stage matrices used by the computer models that will direct this intensive management program.

STUDY AREA

Ponderosa Forest

Since the outset of the 1987 field season the study has been conducted within a 12 by 16 mile parcel of land just southeast of Flagstaff, Arizona. The general area extends east from Munds Park and Mountainaire to Forest Highway 3 (which connects Mormon Lake and Happy-Jack); and south from Lake Mary to Lee Butte (approximately 3 miles north of Stoneman Lake). With the exception of Mormon Mountain which supports a mixed conifer type, the area is a ponderosa pine (*Pinus ponderosa*) forest with a substantial inclusion of gambel oak (*Quercus gambelii*), and occupies an elevational range of approximately 6600 to 7700 feet. During a 1986 pilot study seven observations were obtained in areas outside the one just described. These are similar in elevation and vegetative type, and the observations have been included in our data set.

[1]Paper presented at the Symposium, Multiresource Management of Ponderosa Pine Forests, Nov. 14-16, 1989, Flagstaff, Arizona.

[2]Richard Brown is a Research Biologist, Arizona Game and Fish Department, Flagstaff, Arizona.

All areas are producing annual calf crops in excess of 50 calves/100 cows.

Pinyon Pine/Juniper Woodland

In 1986, six observations were obtained in a P/J Woodland about nine miles northeast of Blue Ridge, Arizona and east of Highway 87. This general area will be used again during the 1989 and 1990 field seasons. It occupies and elevational range of approximately 6400 to 6800 feet and supports Utah juniper (*Juniperus osterosperma*), one seed juniper (*J. monosperma*), alligator juniper (*J. deppeana*), pinyon pine (*P. edulis*) and a small inclusion of ponderosa pine (*P. ponderosa*).

METHODS

During the months of June-August radio marked elk were located at mid-day bedsites between the hours of 10:30 AM and 3:30 PM. Only direct visual observations of animals in a bedded state, or just leaving a bed, were used as a basis for taking measurements. With the exception of cow/calf associations, in which case both sites were marked, only one bedsite per group of animals was used. The bedsite of the radio equipped animal was marked if the elk could be located. If not, the first animal seen was chosen. Estimates of select weather parameters, slope exposure and distance to roads, water and developments were made. The center of the bed impression was used to establish the center of a 16.7 ft. radius circular plot (1/50 acre). The following characteristics were measured for each tree within the plot: Stem diameter (drc for junipers, dbh for other species), height, crown ratio and crown class. Seedlings were initially counted in total. The point centered quarter method of estimating density was later substituted for the total seedling stem count (Cottom and Curtis 1956). A 5.27 foot radius plot (1/500 acre) was nested within the larger plot. This plot encompassed what the animal was bedding on or immediately next to. Within this plot, ocular estimates were made of percent ground coverage by dead and down material and rock.

Canopy closure was measured from the center of the bedsite by means of a concave spherical densimeter held at elbow height. Additionally each bedsite was evaluated for qualification as hiding cover (90% or greater level of visual obstruction at 200 feet or less) by means of an alternately red and white colored sight target (tube) two feet wide and six feet tall (Leckenby et al. 1985). The sight tube was suspended directly over the bedsite. Readings were taken from each of the four cardinal compass directions and averaged into a single value for the site.

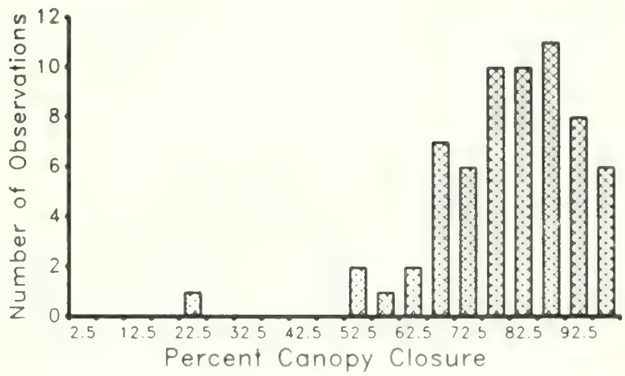

Figure 1. Frequency distribution of Ponderosa pine bedsites within canopy closure classes.

A satellite plot was located 300 yards distant from the bedsite in each of the four cardinal compass directions. Data collection procedures were identical to the bedsite plot except that no sight tube data were collected. The satellite plots were used to demonstrate habitat availability and establish whether elk exhibited selectivity for certain site characteristics.

RESULTS AND DISCUSSION

Ponderosa Forest

Thermal Cover. Canopy closures on the 64 bedsites located through August of 1988 were significantly higher than those on the satellite plots ($p \leq 0.001$). The mean canopy closure of all bedsites was 82% as compared with 42% for all satellite plots. Ninety-one percent of mid-day bedsites occurred within the range of 65-100% (Figure 1). Only 25% of the satellite plots had canopy closures $\geq$ 65% (Figure 2). This demonstrates selection for higher canopy closure.

Elk summer thermal cover is, therefore, described by examining bedsites that possessed a canopy closure of $\geq$ 65%. The few remaining observations (< 65%) are believed to be outliers and are not adequate thermal cover. Average stem diameter was calculated for each of these bedsites. Individual bedsite values were then placed in stem diameter classes compatible with those used by the U.S. Forest Service in the development of the structural stage matrices for the R03WILD model (Byford et al. 1984). Within each diameter class, a mean and range (mean $\pm$ 1 Std. Dev.) was calculated for each structural characteristic

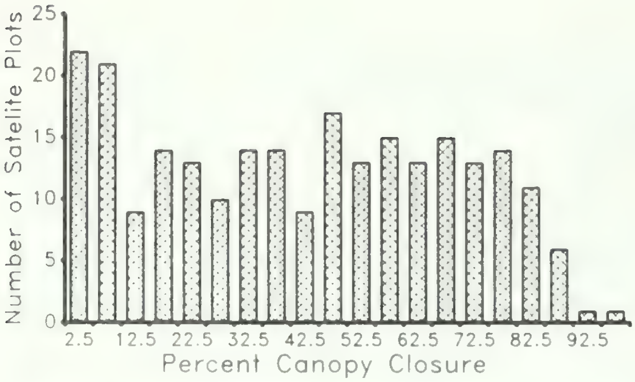

Figure 2. Frequency distribution of Ponderosa pine satellite plots within canopy closure classes.

(Table 1). In order to compare our observations with the ROWILD model, data from Table 1 were transformed and superimposed onto the USFS table of ponderosa pine structural stages (Table 2), as presented in the Wildlife Coefficients Technical Report (USFS 1984). This report recognizes the following structural stages.

Structural Stage	Description	
1	Grass/Forb	
2	Seedling/Sapling	
	Immature	
3a		10-40% canopy closure
3b		41-70% canopy closure
3c		71 + % canopy closure
	Mature	
4a		10-40% canopy closure
4b		41-70% canopy closure
4c		71+ % canopy closure
5	Old Growth	

The shaded areas in Table 2 indicate which structural stages are capable of providing summer thermal cover. The upper and lower boundaries of the shaded area were determined solely on the basis of stems/acre (mean $\pm$ 1 Std. Dev.) within each diameter class (Table 1). No consideration was given to the structural stage classifications 1-5 or a-c. Since the data we used are only from sites with canopy closures $\geq$ 65%, the shaded area should completely cover all "c" classifications and encroach into the "b" classification. About 16% of the "b" classifications should be included because the lower limit was designated at 65% instead of 71%. In all diameter classes our data overlay has missed the lower extremities of the structural stage "c"; and in the 5-7 and 7-9 inch diameter classes, has encroached into the "b" stage by about 50%. This lack of alignment between our data and the designated b and c classification used by the Forest Service is probably unimportant. Greg Goodwin (USFS Biologist, pers. comm.) has indicated that the canopy closure classifications were assigned to the crosswalk table on a best estimate basis and may themselves be slightly out of position.

The R03WILD model uses the previously discussed structural stages to predict wildlife habitat capability. Furthermore, the R03WILD elk matrix for ponderosa

Table 1. Mean values of measures taken at mid-day bedsites with canopy closure > 65%, and occurring in Ponderosa pine forest (mean + 1 S.D.).

Diameter Class (in)	Stems Per Acre	Basal Area	SDI	Height	Canopy Closure	No Bedsites
1.0-4.9	1306.3 (797-1816)	174.9 (123-226)	419.8 (298-542)	17.4 (13-22)	85 (76-94)	n=16
5.0-6.9	703.3 (455-952)	204.7 (143-267)	423.3 (297-550)	29.3 (23-36)	83 (75-92)	n=15
7.0-8.9	452.8 (275-631)	199.7 (112-288)	380.9 (219-543)	29.7 (22-38)	78 (68-87)	n=18
9.0-10.9	300.0 (192-408)	171.9 (107-237)	311.7 (197-427)	32.9 (23-43)	87 (79-94)	n=4
11.0-12.9	250 (179-321)	247.0 (149-345)	402.5 (252-553)	39.3 (30-49)	81 (77-85)	n=2
13.0-16.9						n=0
17.0-19.9	100 (100-100)	186.5 (148-225)	267.7 (223-312)	36.0 (31-41)	85 (68-100)	n=2
20.0-27.9						n=0
28.0>	50 (50-50)	226.2 (226-226)	273.1 (273-273)	78.0 (78-78)	73 (73-73)	n=1

Table 2. USFS structural stages used by elk for mid-day bedsites. Table from Wildlife Coefficients Technical Report (1984).

Ponderosa Pine

Stems Per Acre	Diameter Classes 0-1	1-5	5-7	7-9	9-11	11-13	13-17	17-20	20-28	28+
1-10	1	1	1	1	1	1	1	1	5	5
11-20	1	1	1	1	1	1	4a	4a	5	5
21-40	1	1	1	1	3a	4a	4a	4b	5	5
41-80	1	1	3a	3a	3a	4a	4b	4c	5	5
81-120	1	2	3a	3a	3b	4b	4b	4c	4c	
121-200	1	2	3a	3b	3b	4b	4c	4c		
201-350	2	2	3b	3b	3c	4c	4c			
351-500	2	2	3b	3b	3c	4c				
501-700	2	2	3b	3c						
701-1000	2	2	3c	3c						
1001-2000	2	2	3c							
2000+	2	2								

Stems/Acre (mean + 1 std dev) from elk bedsites in Table 1

Table 3. R03WILD matrix of habitat capability values for elk (USFS 1984).

Ecosystem: Ponderosa Pine

Season of Use: Year-round

Type of Use	1	2	3a	3b	3c	4a	4b	4c	5
	Structural Stages								
Feeding	1	1	1	2		2	5		2
Cover			5	2	1	5	2	1	2

pine (Table 3) shows habitat ratings for cover in all structural stages from 3a-4c and 5. Our data, to date, show elk to use structural stages 2 through 5, but not using the "a" class. The "b" class is also not used below 50% canopy closure. Each structural stage is assigned a 1-5 rating designed to reflect its value as both a feeding area and a cover area. A rating of 1 represents a full acre value of optimum habitat and a 5 represents a 1/5 acre value of the same. Data from this study do not support the R03WILD capability ratings (Table 3).

The current capability ratings could be revised by the following method. There appear to be three breaks in the Figure 1 canopy closure data that would yield functional classes similar to those in the model ("a", "b", "c"). These occur in levels of elk use (no. of elk bedsites) at the 75, 65 and 50% levels of canopy closure. Table 4 gives the frequencies of occurrence for both bedsite plots and satellite plots. Seventy percent of the bedsites occurred at canopy closure levels $\geq$ 75%; 90% at closure levels $\geq$ 65%; and 98% at closure levels $\geq$ 50%. For each of these three categories a ratio was created for the percent of the total observations in the bedsite population to the

Table 4. Frequency of occurrence of bedsites and satellite plots within canopy closure classes.

% Canopy Closure	No. Bedsites		No. Satellite Plots		% Canopy Closure	No. Bedsites		No. Satellite Plots	
0-5	0	2%	22	59%	50-55	2	8%	13	17%
5-10	0		21		55-60	1		15	
10-15	0		9		60-65	2		13	
15-20	0		14		65-70	7	20%	15	11%
20-25	1		13		70-75	6		13	
25-30	0		10		75-80	10	70%	14	13%
30-35	0		14		80-85	10		11	
35-40	0		14		85-90	11		6	
40-45	0		9		90-95	8		1	
45-50	0		17		95-100	6		1	
						n=64		n=245	

Table 5. Ratios of percent use of bedsites to habitat availability (satellite plots).

%Canopy Closure	%Bedsite Plots/Satellite Plots
75-100	70/13=5.4
65-74	20/11=1.8
50-64	8/17=0.47

percent of total observations in the satellite population (Table 5). The ratio relates frequency of use to availability. The quotients clearly demonstrate declining elk use as canopy closure decreases, and suggest that Relative Habitat Capability Ratings of 1, 3 and 11 might be appropriate for 75-100, 65-74 and 50-64% canopy closure ranges in the R03WILD matrix. These values were obtained by dividing each of the three quotients into the first. There is nothing in our current data base to suggest that canopy closures < 50% provide any useful level of thermal cover. However, one addition to the matrix is made. Structural stage 2 is apparently capable of producing high quality thermal cover. At least 14 of the 16 observations in the Table 1 data for the 1.0-4.9 diameter class had canopy closure levels $\geq$ 75%.

The study plan calls for analysis of stem density and diameter data in an attempt to identify elk thermal cover without the use of direct canopy closure estimates. An amendment to the new Forest Plan for the Coconino attempts to define thermal cover in terms of either growing stock level or basal area within diameter classes. McTague and Patton (1989) have suggested that Stand Density Index values might provide a more precise description than basal area. Upon obtaining a complete data set, we will examine any relationships that might exist.

Hiding Cover. The R03WILD matrices treat cover as a general entity, making no distinction between thermal and hiding cover. Although existing definitions for each are quite clear; in practical application it is frequently difficult to separate the two. From this study, 70% of all bedsites with canopy closure $\geq$ 50% qualified as hiding cover, and 60% of those with canopy closures $\geq$ 65% also qualified. Since in the former case we are dealing with 98% of the bedsite population, during the summer months primary selection is obviously for thermal rather than hiding cover. The following is not intended to detract from the importance of hiding cover, particularly since many animals will still be on summer range when the hunting

seasons begin. However, it does suggest that hiding cover alone is of limited value during the summer months as adult elk do not use it for extended periods of time due to the existing thermal conditions. If we accept 50% canopy closure as the minimum threshold for thermal cover, only one bedsite from our entire sample occurred in hiding cover alone. This seems to suggest that on summer range, the full cover compliment should exist in the form of thermal cover that has an adequate hiding cover component within it. The R03WILD model may already be oriented in that direction. Matrix cells which have cover values inserted, all seem to have been selected on the basis of thermal cover (Table 3). Structural stage 2, with its potential for high stem densities and obvious hiding cover capability, was not selected.

Two radio locations per month have been obtained for each study animal. These will enable us to construct summer home range boundaries. Aerial photo interpretation can then be used to determine existing thermal cover/forage area ratios within the seasonal home ranges. This information will be included in the final report. But, it will not tell us what percent of any seasonal home range qualifies as hiding cover.

Bedsite Species Composition. The accepted definition of summer thermal cover restricts all considerations to coniferous species. On our study area two deciduous species (Gambel Oak and New Mexico Locust) occur in noticeable quantities. Gambel Oak in particular contributed heavily to both the canopy closure readings and the stem density and mean diameter values assigned to the bedsites (Table 6).

Table 6. Mean basal area of bedsite plots (sq. ft/acre) within species and diameter classes.

Species	Diameter Class 1.0-4.9	5.0-8.9	9.0-12.9	13.0>
Pinus ponderosa	125.7	170.5	187.5	134.4
Abies concolor			22.6	
Cowania mexicana	.4			
Robinia neomexicana*	7.4			
Quercus gambeli*	112.2	64.8	34.1	195.9
TOTAL	245.6	235.3	244.2	330.3
% Deciduous sp.*	49	28	14	59

SUMMARY

Ninety-eight percent of elk mid-day bedsites occurred where canopy closures were $\geq$ 50%. Relative habitat capability ratings for the canopy closure classes of 50-64%, 65-74% and 75-100% appear to be 1/11, 1/3 and 1/1 (full) acre value; and might be appropriate for use in the R03WILD modeling process.

Seventy percent of our thermal cover sites also qualified as hiding cover. However, selection was primarily for thermal characteristics as 98% of all observations occurred when some level of thermal protection was present. Gambel oak was a significant component of the vegetation at bedsites.

SCHEDULE

The Final Report is due June 30, 1991. Field work in ponderosa will terminate August 31, 1989. Target levels for the summer of 1989 are 30 ponderosa and 30 P/J bedsites. Target level for the summer of 1990 is 30 + bedsites in P/J.

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Scheduling Timber Harvests for Wildlife, Allowing Well-Defined Violations to Age Class Nonadjacency Constraints[1]

Thomas E. Gross and Dennis P. Dykstra[2]

Abstract.--We give an overall view of our results on generalizing the geometric effect of maintaining a minimum difference in age class between any two adjacent timber stands scheduled for harvest on any map, over the length of a rotation. Then we analyze the effect of systematically relaxing this constraint on minimum age difference.

INTRODUCTION

Many national forest plans specify that areas where harvesting is allowed be put into regulation through the establishment of small evenaged timber stands. Each forest is divided into units called management areas, compartments, blocks or some other title which implies an area of approximately 5000 to 20,000 acres. These larger areas are to be entered for the purpose of harvesting timber on a regular interval, often 10 years. A number of the timber stands (which are usually around 60 acres) in each compartment are to be harvested individually during each entry, thereby establishing a cohort of evenaged (regenerated) stands comprising an age class. In most of the plans where "nonadjacency constraints" are defined, stands of the same age class must not be adjacent. In addition, many forest plans state that stands spanning several age classes cannot be adjacent. This process is intended to provide an increasingly diverse habitat for wildlife as the compartment is brought into regulation. We call these rules that restrict the age class difference between neighboring timber stands Temporal Nonadjacency Constraints.

Our preliminary work (Gross 1989, Gross and Dykstra 1989) established that the strict imposition of constraints on the adjacency of timber stands in order to enhance the horizontal and vertical diversity of the vegetative overstory was impractical. We found this to be so for several reasons. Most important was the extreme difficulty of using mathematical programming to find optimal economic management regimes for an area made up of small evenaged stands while adhering to even the simplest constraints on age-class juxtaposition throughout an entire rotation. In addition, finding even a feasible harvest schedule for an area made up of stands all having the same "worth" in terms of economic return or physical production while maintaining both a non-declining even flow and constraints on adjacency was not practical using mathematical programming. However, our research did show some of the temporal and spatial patterns brought about by several different adjacency constraint formulations when applied to the same map. We also calculated a simple index of spatial and temporal diversity that can be used to compare the patterns produced over time for different rigidly-enforced nonadjacency constraints. The diversity index of a map that had all of its stands scheduled for harvest without violating the adjacency constraint was compared to the index computed for the same map with the same number of age classes where harvest dates were randomly assigned. This paper explores the middle ground between strict application of adjacency constraints and random assignment of harvest dates by showing what happens when well-defined violations of temporal nonadjacency constraints are allowed to occur during a rotation.

METHODS TO RELAX NONADJACENCY CONSTRAINTS

Some forest planners and wildlife biologists realized that strict compliance to stated constraints on adjacency of regeneration cuts might severely restrict options for the placement and timing of those harvests. They could foresee

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in general what we later showed specifically (Gross and Dykstra 1989, Gross 1989). For instance, in our initial research we found that a schedule of final removal cuts strictly following nonadjacency constraints outlined in the Kaibab National Forest plan may require up to 140 years before the stands cut in the first entry could again be harvested. The assumed biological rotation age on the Kaibab is 120 years. The nonadjacency rules lengthen this biological rotation age by 20 years at the outset. Even achieving the regulation of a tract in 140 years comes with several built in suppositions. Most important is that the entire 140-year schedule be planned before initial harvests are begun, and be strictly followed throughout the first rotation. Initial volume targets based on the constraint of non-declining evenflow can only be implemented after it is known whether the geometric and spatial pattern demanded by the nonadjacency constraints allows the anticipated flow over a series of harvests from stands very likely to contain different volumes of timber. Failure to account for the geometry over the entire rotation may cause the violation of non-declining evenflow even if the timber volume to sustain the initial target is present when the violation occurs. This volume may merely be in the wrong place. Furthermore, any deviation from the schedule once it is begun (e.g., one of the stands to be logged in year 40 burns in year 19) is very likely to lengthen the rotation age for the area, and the harvest of some stands will be deferred well into what was to be the second rotation period.

A general realization of the kind of difficulty mentioned above may have prompted planners (Forest Service 1987a and 1987b) and wildlife biologists (Salwasser and Tappeiner 1981) to state adjacency guidelines in less restrictive ways, as in the following extract from the Coconino National Forest plan (Forest Service 1987a):

> The following minimum factors are considered in obtaining stand diversity. *The presence of one or more of these factors constitutes a difference between stands.*
> - Stand age - ± 20 years difference in measurable age.
> - Density- ± BA 30 ft^2
> - Average Stand Diameter - ± 4 inches. If average stand diameter is larger than 18 inches, then this parameter will not be used.
> - Species composition differences are determined by the ID team, *depending on the project or sale objectives.* Overstory and/or understory species are evaluated.

The sentence between the asterisks is from an amended version of the 1987 plan. Italics are added for emphasis.

From the Kaibab National Forest plan (1987b):

> To improve horizontal diversity, *avoid* seed cuts in stands adjacent to a seedling stand, sapling stand, or a stand in regeneration.

We interpret this to mean a ± 30 year age difference between adjacent stands.

From Salwasser and Tappeiner (1981):

> Regeneration should be scheduled so that adjacent stands have *at least 80 percent of their common boundary* with at least a two decade age difference.

Discussion of the Coconino Nonadjacency Constraints

The first three Coconino National Forest constraints would give a mathematician who specialized in set theory, combinatorics, and forestry a good deal of work drawing general conclusions about the union of three interrelated non-independent sets. The fourth constraint will cause environmental groups to question the degree of intent on the part of the Coconino to implement any of the previous three, since vegetative species diversity and diversity in the ages (or densities or average diameters) of a collection of stands (of an assumed single species) are two different measurements. If the aim of nonadjacency constraints is to promote a diverse habitat for wildlife by juxtaposing a collection of small land areas so that any neighboring pair differ in the size and density of the overstory, then a measure the resulting wildlife species diversity is more appropriate as an alternative measure rather than plant species diversity.

Yet, there is an explicit temporal nonadjacency constraint (the first), and there are two implied temporal nonadjacency constraints (the second and third). Whatever constraints apply, all the neighbors of an individual stand must comply, even if for different reasons.

The Constraint on Basal Area

Whether or not a newly regenerated stand will reach a basal area of 30 ft^2 in 20 years is a predictor subject to high variability. A stand containing 1000 trees per acre of 3 in average diameter would have 49 ft^2 of basal area. A stand containing 600 trees per acre of 3 in average diameter would have about 30 ft^2 of basal area. A stand containing 120 trees per acre (the minimum acceptable stocking level) of 4 inch average diameter would have about 10.5 ft^2 of basal area. Such a minimally acceptable stand would not reach 30 ft^2 until an average stand diameter of 6.8 inches occurring somewhere near year 40 (Pearson 1950), assuming no mortality. Using the value of 400 surviving seedlings (Larson and Minor 1983, Heidman 1988) an average diameter of 3.7 inches

would have to be attained in 20 years to make the second nonadjacency constraint binding.

The Constraint on Average Diameter

A reading of Pearson (1950) leads to the conclusion that southwestern ponderosa pine is unlikely to reach an average stand diameter of four inches in 20 years. On average both the basal area constraint and the average diameter constraint could be expected to be redundant to the constraint on age difference.

All three of the single species attributes (age, density, diameter) can be changed in existing stands, not just upon establishment of a newly stocked stand. If a stand consists of an old growth overstory and a 70 year old understory, it can be changed in "age" from 200+ years old to 70 years old by removing the overstory. Average stand diameter and basal area are always changed when thinning occurs, and some precommercial or commercial thinning could be delayed. However, no "mid-rotation" change in a stand attribute will remove an adjacency conflict due to the establishment of a newly regenerated stand; only the passage of time or a "finding" of differing "species diversity" by the ID team can do that.

We conclude that the Coconino must rigidly apply a 20 yr. minimum age difference in establishing new evenaged stands.

Discussion of the Kaibab Nonadjacency Constrains

Although words like "avoid" are guaranteed to attract the attention of those who doubt that any actual avoidance will occur, the Kaibab's nonadjacency constraint precisely states the only practical way to take stand adjacency into account. What remains is to find an acceptable measure of avoidance.

Discussion of Salwasser and Tappeiner Nonadjacency Constraints

Salwasser and Tappeiner (1981) introduce the way many forest planners try to deal with the uneasy feeling that nonadjacency constraints may be too binding on site specific management. If a well-defined level of constraint violation can occur, then those constraints may not reduce the annual allowed harvest or extend the rotation age. In this way the Kaibab could "avoid" the minimum rotation age of 140 years that results from the strict application of their nonadjacency constraints (Gross 1989).

Several difficulties arise in the interpretation of the Salwasser and Tappeiner (1981) nonadjacency constraints. As quoted, Salwasser and Tappeiner seem to be saying that a single pair of stands must have 80% of that particular stand-to-stand boundary in compliance. This state of affairs is a bit difficult to imagine, since either one of the pair is harvested in its entirety or it is not, and if not, either there has been no harvest or a third "new" stand has been created that makes up the 20% of the former stand-to-stand boundary that can be in noncompliance (and therefore harvested). This sort of "when is a stand not a stand - argumentum ad infinitum" belongs in the realm of metaphysics, not forest planning. It leads to doughnut-shaped stands suddenly appearing on stand maps or a pattern of clearcuts with narrow buffer areas between them. Our results indicate that neither of these strategies circumvent nonadjacency constraints (Gross and Dykstra 1989, Gross 1989).

If we amend the rule and state that as a minimum, 80% of each stand's entire boundary must comply with the stated 20 year age difference there are still problems. By specifying a percentage of a stand's lineal boundary that must comply, a continuous function is applied to a set of discrete entities, namely the set of stand-to-stand borders a particular stand has. Outcomes for this 80% rule will be different for different stands. For a stand that has few neighbors perhaps none of its shared boundaries can be in violation, and for a stand having many neighbors perhaps three or more of its shared boundaries will be freed from the nonadjacency rule. To allow a percentage of each stand's boundary to be in noncompliance creates a desirable characteristic of flexibility in meeting the dispersion goals for management areas with different spatial arrangements. But, the percentage approach immensely complicates the already immensely complicated task of actually assigning harvest dates to a collection of timber stands.

An Alternative to the 80% Rule

We analyzed constraint relaxation using the same basic approach as Salwasser and Tappeiner (1981). We assume that the idea of having at least 80% of and stand's boundary in compliance with some stated nonadjacency constraint represents a consensus among wildlife biologists. Instead of using some percentage of an individual stand's boundary as the compliance target, we restrict the number of neighboring stands that may fail to meet the minimum age class difference specified in the nonadjacency constraints. Over the entire compartment (management area, or 10k-block), the average compliance using this method can approximate the 80% rule for the following reasons.

> Although individual stands may have more or fewer, the map-wide average for the number of neighbors per stand can be no greater than six (Ore 1963).
>
> The average number of neighbors per stand for a typical stand-map will be around five, if the stand boundaries shared with stands in the adjacent compartment are not taken into account.

Therefore, by allowing one nonadjacency constraint violation per stand, the 80% rule will be met on average (i.e. approximately one out of five shared boundaries) within the compartment as a whole. For this analysis we assume the any compartment-to-compartment violations will not be taken into account.

METHODS

Definitions and Assumptions

In order to draw some general conclusions about the effect nonadjacency constraints and the permitted violations of these constraints will have on harvest scheduling, non-declining even flow, economic optimization, and rotation ages of forest areas managed primarily for timber production, we need to define the terms of the analysis and clarify assumptions.

Definitions:

Age Class. A group of individual timber stands each containing trees that are considered to be the same chronological age or within a small well-defined range of age.

Harvest Entry. A planned return to an area for the removal of mature timber. The harvest entry may also be called simply an "entry".

Timber Stands. Tracts of timber land that are harvested with the goal of timber production and regeneration (clearcut, shelterwood cut, seedtree cut) or left standing until some future harvest entry.

Compartment, Management Area, 10-k Block. The area of land over which stand-level planning is done.

Temporal Nonadjacency Constraint. Any rule that stipulates a minimum difference in age between any timber stands that are geographically adjacent. The term "adjacency constraint" is synonymous.

Exclusion Period. The age a recently regenerated stand must attain before any of its immediate neighbors can be harvested. The exclusion period is denoted by E.

Return Period. The time period that elapses between two successive harvest entries into a management area, 10-k block, or compartment; also called "harvest entry period", "entry period", or sometimes the "cutting cycle." The entry period is denoted by R.

Timber Rotation Age. The time that elapses between the establishment of a new timber stand and the maturity of that stand. Maturity can be in biological or economic terms. The term "rotation age" is taken to mean the timber rotation age not the nonadjacency rotation age.

Nonadjacency Rotation Age. The minimum amount of time that must elapse between the establishment of a timber stand (upon the removal of the previous overstory) and its subsequent second harvest, purely as a consequence of the imposition of temporal nonadjacency constraints. This "minimum" amount of time is actually a "maximal minimum"; it is a "worst case" minimum, and specific maps may have nonadjacency rotation ages that are less than this theoretical minimum.

Planning Horizon. The time span over which a solution to a mathematical programming formulation is generated.

Area or Volume Regulation. The goal of harvesting approximately an equal area of land or equal volumes of mature timber during each harvest entry.

Number-of-Stands-Per-Entry Regulation. The type of regulated condition imposed by adjacency constraints. If an equal number of timber stands can be harvested during each harvest entry, all stands in a compartment would have to contain equal volumes of timber or be of equal area to achieve volume or area regulation.

Nondeclining Even Flow. The desire to sustain fairly even yearly timber yields in perpetuity without a decline in volume (Dana and Fairfax 1980).

Assumptions:

1) All timber stands are assumed to be in mature condition, and able to be harvested.

2) All timber stands in the compartment are candidates for harvest. Any stands that are to be excluded, for any reason, are not represented in the analysis.

3) A regulated forest of small evenaged timber stands is the goal.

4) Upon regulation, each stand is harvested again when it reaches rotation age.

5) The harvest and regeneration of each stand occurs simultaneously.

6) The harvest entry period is constant over a rotation, and all stands chosen for harvest

are to be cut at the beginning of each harvest entry. Each time a harvest entry occurs, a cohort of new stands belonging to the same age class is established

7) The economic "worth" or volume contained in each stand is equal. That is; all stands are equally desirable as candidates for harvest in any harvest entry.

8) The harvest of an approximately even number of stands during each harvest entry is an option, and the analysis can be run with or without this condition.

9) The harvest of one or more timber stands is to occur during each harvest entry during a rotation.

These assumptions certainly represent an idealized view of forest management directed toward the sustainable production of timber with the consideration of wildlife via nonadjacency constraints, but without regard to physical production or economic optimality. For some nonadjacency rules, maps of arbitrary size can be drawn that will never meet the ninth assumption (Gross 1989).

Study Goal

This analysis has one simple-to-state goal. Find the minimum number of age classes necessary to allow the assignment of a harvest date to every timber stand represented on any stand map without violating the stated nonadjacency constraint more than one time per stand. In other words, remove all other constraints on the selection of any stand at any time except the relaxed nonadjacency constraints. Given this goal, the assumptions stated above ensure that the problem is formulated in its simplest terms. As a result, a more complicated (typical) problem formulation can be expected to dictate that as many, if not more, age classes be used. The total number of age classes necessary to assign a harvest date to every stand in a compartment without breaking the nonadjacency rules (even the relaxed rule just stated) determines the nonadjacency rotation age.

Coloring Maps

Assigning a harvest date to individual timber stands subject to nonadjacency constraints can be thought as a map coloring problem. Specifically, this type of problem has been given the name "chromatic scheduling" (Wood 1969). Map coloring is a legitimate area of mathematics; contrary to the impression of those who insist on giving us boxes of crayons and coloring books. It is included in the mathematics of graph theory. Graph theory provides the mathematical framework covering most allocation, scheduling and network problems.

Our work is an extension of what is called the four-color theorem. The infamous (at least to mathematicians) four-color theorem remained one of the great unsolved problems in mathematics until Appel and Haken (1977) completed a proof which capped a century of work by many mathematicians. The four-color theorem is simple to state; "To color all the regions of a map drawn on a plane or sphere so that no neighboring regions are given the same color will never demand the use of more than four colors." Proving that there was no counterexample to this claim was very difficult.

Coloring Maps with Strict Adherence to Nonadjacency Constraints

We formulate our map-coloring problem by using the definitions of the return period, "R" and the exclusion period, "E" stated above. Find E/R, and if this quotient is not an integer raise it to the next higher integer value. For instance, the Kaibab constraints are interpreted to require a 30 year exclusion period. If individual compartments on the Kaibab are entered every 30 years for harvesting, then E/R = 1, and each time a harvest entry is made a new 30-year age class is established. If a map is prepared using, say, the color red for all stands that will be harvested in the first entry, the color blue for all stands that will be harvested in the second entry, and so on, the four color theorem says that we will never need more that four colors to fill in the stand map so that two red-colored stands are never adjacent, etc. Since each color represents the span of 30 years, the Kaibab nonadjacency constraints will not be violated as long as the map is "properly" colored using the colors that represent the four 30-year age classes. Four 30-year age classes means a nonadjacency rotation age of 120 years, which coincides with the assumed biological rotation age on the Kaibab of 120 years. Note that 4*(E/R) gives the number of age classes that may be needed to color the map. Since the "span" of each age class is R, simply multiplying 4*(E/R) by the number of decades or years defining R gives the nonadjacency rotation age.

Perhaps the establishment of only four age classes in a mosaic on the landscape is not considered to be "diverse" enough. A fifth or sixth age class (color) could be added, but the nonadjacency rotation ages would become 150 and 180 years; found using 5*(E/R)*R and 6*(E/R)*R. However, there is another way to provide more age classes, and that is by setting the return period to be less than the exclusion period.

Again, we use the Kaibab nonadjacency constraints where E remains 30 years, but now we let R = 10 years. The ratio, E/R becomes 3, and we may conjecture that the number of age classes called for will be 4*(E/R) or 12, and that the nonadjacency rotation age will remain 4*(E/R)*R or 120 years. Unfortunately, it is easy to provide a map that cannot be colored using the 12 age

classes. So the number of colors that will be needed to color any possible map when $\underline{E}/\underline{R} = 3$ will be more than 12.

Suppose we pick one of the stands on a stand map and assign it a harvest date of 60 years from the present. As shown above, when the exclusion period was the same as the return period, $\underline{E}/\underline{R} = 1$, and $\underline{E} = 30$, four age classes are needed to "color" the map. Adjacency conflicts can be avoided by simply assigning to the stand's neighbors one of the three other age classes (i.e. years 0, 30, or 90). However, if the exclusion becomes three times the return period, ($\underline{E}/\underline{R} = 3$, $\underline{R} = 10$, and $\underline{E} = 30$), there will be several age classes that cannot be assigned to the neighbors of the stand that was just assigned a harvest date of year 60. Instead of only year 60, the years 40, 50, 70, and 80 are also prohibited from being assigned to any neighboring stand. We have assumed that it is desirable to have all age classes represented somewhere on the stand map, and the result is that as many as 14 10-year age classes will have to be used to completely color an arbitrary stand map (Gross 1989). This means that the nonadjacency rotation age for the Kaibab, if the constraints are rigidly enforced, is 140 years, as opposed to a biological rotation age of 120 years. In other words a "cost" is paid for the benefit of having 14 10-year age classes juxtaposed on the stand map rather than just four, but this is much less than the cost of providing 14 distinct 30-year age classes.

The Kaibab example serves to show a difficulty in the practical application of the definition of the nonadjacency rotation age. Having a nonadjacency rotation age of 140 years means that <u>any</u> map, no matter how cleverly drawn, can be completely "colored" to meet the rules with <u>no more</u> than 14 10-year age classes. Although we can easily draw a rather convoluted strange-looking map that does, indeed, demand that 14 colors be used, most everyday stand maps can be colored with 13 age classes, and often with 12 age classes. For instance, a checker board stand map can be colored to meet the Kaibab nonadjacency constraints using no more than seven 10-year age classes (Mealey et al. 1982). To go on and assume that <u>all</u> maps can be scheduled with seven age classes (Mealey et al. 1982) is an error.

Suppose, that upon reflection, it is concluded that humans armed with sophisticated measuring equipment might have a difficult time discerning the "edge effect" between two successive age classes out of 14 naturally regenerated age classes, let alone the wildlife, and that fewer age classes would suffice. The Coconino's temporal nonadjacency constraint having an exclusion period of 20 years coupled to a return period of 10 years may provide a suitable number of age classes. In this case $\underline{E}/\underline{R} = 2$, and the hypothetical stand on the map scheduled to be harvested in year 60 would only be proscribed from being next to stands harvested in years 50, 60, and 70. Again, if we assume that some stands somewhere on the map should be assigned harvest dates of years 50 and 70, the number of age classes needed to color the map will be nine (Gross 1989). Nine age classes each spanning 10 years will give the Coconino National Forest a nonadjacency rotation age of 90 years. Since the Coconino's assumed biological rotation age is 120 years they may be spared the situation of having to "avoid" violating their nonadjacency constraints. This is fortunate, since their current plan assumes strict adherence to the rules. The Kaibab could also implement adjacency constraints where nine age classes are all that is required to color their stand maps. If their exclusion period remains 30 years and a return period of 15 years is used, then 9 age classes will be needed. This gives a nonadjacency rotation age of 135 years.

The Kaibab has made a nonadjacency rule based on an exclusion period that is <u>one-fourth</u> the biological rotation age. If the nonadjacency constraints are strictly enforced, the Kaibab will not be able to juxtapose more than four age classes, (where $\underline{E}/\underline{R} = 1$), of small evenaged timber stands without exceeding the desired biological rotation age of 120 years. On the other hand, the Coconino has an exclusion period that is <u>one-sixth</u> the biological rotation age. As a result, the Coconino can implement four age classes in a rotation age of 80 years, nine age classes in a rotation age of 90 years, or even 14 age classes in a rotation age of 98 years (the next higher integer value of (20/3) times 14). Therefore the Coconino seems to have much more flexibility in the actual implementation of a harvest schedule.

There are two other results of our previous work (Gross 1989, Gross and Dykstra 1989) that diminish any apparent advantage the flexibility of a shorter nonadjacency rotation age would give the Coconino over the Kaibab in setting up an optimal harvest schedule while strictly following nonadjacency constraints. By optimal we mean that the compartment produces the maximum amount of timber possible or the most valuable amount of timber.

1) Provided the compartment is to be modeled using mathematical programming (e.g. FORPLAN), the attainment of a regulated forest within the nonadjacency rotation age or the maintenance of nondeclining even flow over a rotation, demands the use of a planning horizon that is at least the length of one full nonadjacency rotation.

Every stand in the entire compartment must have a harvest date assigned before harvests are begun or there will be no guarantee that unscheduled stands will be in the correct locations at the correct time relative to stands already scheduled. Any stands that are not in correct locations at some future date may have to be given harvest dates that are beyond the end of the nonadjacency rotation age. If a schedule of harvests in a compartment on the Coconino is

made using a 40 or 50-year planning horizon instead of the 90-year planning horizon dictated by the nonadjacency rotation age, the logging of some stands that were not assigned to the harvests planned from years zero to 50 might have to be delayed beyond 90 years, and possibly past the 140 year nonadjacency rotation age of the Kaibab. Because of the restrictive effect of nonadjacency constraints on spatial arrangement, once an extended rotation is forced upon them, planners, at some future date, will be unable to shorten future rotations down to the minimum attainable on the Coconino. The effect on yearly volume predictions can be nothing other than negative from the point of view of timber production. No meaningful estimate of sustainable yield can be made unless the spatial arrangement of all the stands available for timber production is taken into account for as long as it takes to have one harvest occur in each of these stands.

Even if a forest planning team was willing to plan a schedule of harvests for a compartment over a full nonadjacency rotation, there would be extreme difficulty in ever changing the schedule once it is put into motion without extending the rotation age. Therefore the planners would not only have to be willing to plan, but they would have to be willing to believe that their schedule would actually come to pass precisely as predicted.

2) It is virtually impossible to model an optimal harvest schedule while implementing nonadjacency constraints for more than a few stands by using mathematical programming (Garey and Johnson 1979). If our definition of "optimal" is simply to log every timber stand in a compartment in the shortest period of time without ever violating a nonadjacency constraint, no method known can promise to produce this optimal harvest schedule of discrete entities (timber stands) any more efficiently than a blind search through all possibilities (Lawler 1976, Garey and Johnson 1979). Other definitions of optimal (e.g., maximum physical production or maximum economic return) are as difficult as the simpler problem just stated. Problems of this type are formally known in applied mathematics as NP-complete (Lewis and Papadimitriou 1978, Stockmeyer and Chandra 1979, Hopcroft 1984, Karp 1987, all are excellent articles and not extremely technical).

Although we can state precisely how to do so, and we can show that the process definitely has a solution, no algorithm exists that can guarantee finding an optimal solution to a map coloring problem that is more than about 20 regions in size within a "reasonable" amount of time. We attempted to color a 48-region map to meet the Coconino nonadjacency constraint by using only eight colors. We sought only a "feasible" solution (all regions were of equal "worth"), and formulated the problem as a 0-1 integer program using a branch and bound algorithm. This design meant that the first feasible solution the algorithm "ran into" would be good enough. In this case any "feasible" solution is equivalent to an "optimal" solution. The problem ran for over seven days of central processing unit time on a Digital Equipment VAX 8350 [1] computer without finding a solution, or even indicating whether there was a solution (Gross and Dykstra 1989). We later successfully colored this map to meet the 8-color conditions outlined in the mathematical programming formulation, but we did so by hand - in about an hour. We found out in practice what others found in theory (Garey and Johnson 1976, Garey and Johnson 1979).

Allowing exceptions to nonadjacency constraints will not alleviate the two problems mentioned above. We continue only as an academic exercise, and with the vain hope that current attempts to reduce constraint sets for FORPLAN formulations of nonadjacency constraints or any other device to find optimal regimes will also be looked upon as merely academic exercises (Meneghin et al. 1988).

To summarize our previous results for the number of age classes necessary to comply fully with three nonadjacency constraint formulations:

1) If the exclusion period and return period are the same; $\underline{E}/\underline{R} = 1$, no more than four age classes will ever be required to assign a harvest date to all stands on an arbitrary stand map, and the nonadjacency rotation age will be $4*\underline{R}$.

2) If the exclusion period is twice the return period; $\underline{E}/\underline{R} = 2$, no more than nine age classes will ever be needed to assign a harvest date to all stands drawn on an arbitrary stand map, and the nonadjacency rotation age will be $9*\underline{R}$.

3) If the exclusion period is three times the return period; $\underline{E}/\underline{R} = 3$, no more than 14 age classes will ever be needed to assign a harvest date to all stands shown on any arbitrary stand map, and the nonadjacency rotation age will be $14*\underline{R}$. Actually, all maps we have analyzed can be colored with 13 colors, but we will use the more conservative estimate.

The number of age classes required can be calculated by the formula:

$$\text{Age Classes} = 5*(\underline{E}/\underline{R}) - 1.$$

Coloring Maps When Nonadjacency Constraints Can Be Violated

Permitted Violations

As previously stated, a compartment-wide 80% compliance with nonadjacency constraints will be met, on average, if only one stand-to-stand boundary violation is allowed per stand per rotation. This rule must be further defined when $\underline{E}/\underline{R}$ is greater than one, since there is more than one type of stand-to-stand violation possible when $\underline{E}/\underline{R}$ = 2 or $\underline{E}/\underline{R}$ = 3.

The only possible violation when $\underline{E}/\underline{R}$ = 1 is to harvest adjacent stands during the same harvest entry. When $\underline{E}/\underline{R}$ = 2 not only is there a noncompliance when an adjacent stand is harvested during the same entry, but also if an adjacent stand was harvested during the previous entry or is scheduled to be cut in the next entry. A "next entry" violation is equivalent to a "previous entry" violation if it is expressed from the point of view of that particular neighboring stand scheduled for the "next" entry. A manager may further specify that the single violation permitted is to occur <u>only</u> during the <u>same</u> harvest entry, or <u>only</u> with a stand cut during the <u>previous</u> harvest entry, or with one neighbor logged during <u>either</u> the same or pervious entry. When $\underline{E}/\underline{R}$ = 3 the situation gets more complicated. Again, whether a violation is "previous" or "subsequent" depends only on the harvest date of the particular stand on which the time measurement is based. The single violation can occur if a neighboring stand was harvested two entries before, or one entry previous, or during the same harvest entry. Further specification may state that the violation be only with a stand harvested two periods previous, or only with a stand harvested one period previous, or only with a stand logged during the same period, or only with a stand harvested during one of the three pair-wise combinations of; two previous, one previous, and same period, or, finally, one violation with any of the three.

Some of the "violation rules" just stated make much less sense than others, and so where ignored in this analysis. For example, it makes little sense to permit the single stand-to-stand violation to be either with a neighbor scheduled for harvest two harvest entries previous or with a neighbor scheduled for the same harvest entry, but not with an adjoining stand scheduled for the previous entry. Likewise, when $\underline{E}/\underline{R}$ = 2 or 3, to permit noncompliance to occur <u>only</u> with a stand scheduled for the same period will cause more serious degradation of edge-to-edge age class difference than accepting an infringement along the border of a stand cut one or two entries previous. Another nonsensical twist to the problem would be to say that there <u>must</u> be one stand-to-stand violation of the nonadjacency constraints. We obviously want the option tc observe the rules where we can, and only break them when we must.

Below is a more formal listing of violations studied. Each of these possible violations is from the viewpoint of whether or not the timber stand being considered for harvest in the current entry period (the referenced stand) can be cut without violating the adjacency constraints of more than one of its neighbors which has been harvested previously.

When $\underline{E}/\underline{R}$ = 1

> One neighboring stand can be harvested during the same entry period as the referenced stand.

When $\underline{E}/\underline{R}$ = 2

> One neighboring stand can have been harvested <u>only</u> during the entry period previous to the entry period of the referenced stand.
>
> One neighboring stand can have been harvested during the entry period previous <u>or</u> during the same entry as the referenced stand.

When $\underline{E}/\underline{R}$ = 3

> One neighboring stand can have been harvested <u>only</u> during the entry period that was two entries previous to the harvest date of the referenced stand.
>
> One adjacent stand can have been harvested <u>either</u> during the entry that was two entries previous <u>or</u> during the entry period immediately before, but <u>not</u> during the harvest entry of the referenced stand.
>
> One adjacent stand can be harvested during the same harvest entry as the referenced stand <u>or</u> the previous entry <u>or</u> two entries before the referenced stand.

Given these rules, the goal is to find the fewest age classes (or, equivalently, harvest entry periods) that will ever be needed to completely schedule (or color) an arbitrary stand map.

Methods Used

Given the four color theorem, if $\underline{E}/\underline{R}$ = 1, and one boundary per stand can be in noncompliance, then simple logic will dictate the fewest age classes necessary. For problems where $\underline{E}/\underline{R}$ is greater that one, and one stand-to-stand border can break the nonadjacency rules, an empirical approach was used to estimate the shortest nonadjacency rotation. The method is simply to color one or more "hard-to-color" maps manually while using the fewest colors possible.

The number of colors found by the empirical method cannot be taken as a guarantee that some counterexample (a map requiring more colors) will never be found. We offer our estimates only as a "strong conjecture" and base them on our experience in map coloring and our reading of the methods used in proving the four color theorem (Appel and Haken 1977). We have reason to assert that conclusive proofs are possible for problems in map coloring where E/R is greater than one (Gross 1989), and that results will be the same as those presented below. The number of age classes necessary to schedule the future harvest of any compartment under the assumptions stated above must be taken as a "working minimum".

RESULTS

When E/R = 1

The only possible violation, when E/R = 1, is to cut in adjacent stands at the same time. If the number of violations per stand is limited to one, then only adjacent pairs of stands can be in violation in any entry, since the single infraction allowed for one of the pair is also the only infraction allowed for the other. All stands surrounding the pair in noncompliance must not be harvested in the same entry. This situation is equivalent to erasing the stand boundary between the two noncomplying stands. Many pairs of stands could be chosen in the first entry, and many more could be chosen in subsequent entries. But, since these pairs become, in effect, one larger stand that must adhere to the nonadjacency constraint, the number of age classes, and hence, the nonadjacency rotation age will not be reduced. For the same reason, the nonadjacency rotation age for any value of E/R will not be reduced if the only infraction allowed per pair of stands is a "same-period to same-period" violation.

When E/R = 2

As stated above, the single violation of nonadjacency rules can happen with a stand that was harvested in the previous harvest entry, or with a stand harvested either in the same harvest entry or in the preceding entry. In the first case, the number of age classes (colors) will be lowered by two from nine to seven. In the second situation, the number of age classes will also be lowered from nine to seven. So, the Coconino can lower its nonadjacency rotation age from 90 years to 70 years using either constraint relaxation. The reason the number of age classes was not lowered further by the second relaxation is because, like the four color case above, a same-period to same-period violation only "erases" the stand-to-stand boundary of the noncomplying pair.

When E/R = 3

Strict compliance with the rules can be broken by cutting a stand next to a stand that was harvested two entries previous, or with a stand harvested either two or one harvest entries before, or with one stand cut in one of three entries; the current, one before, or two previous.

In the first case, the number of age classes needed goes from 14 to 12. For the second, 11 age classes will suffice. As in the examples when E/R is two or one, the number of age classes necessary will remain at 11 for the third combination of possible violations. Like the Coconino, the Kaibab would find that the nonadjacency rotation age has dropped. In the first allowable relaxation, the nonadjacency rotation age becomes 120 years which is the assumed biological rotation age. The nonadjacency rotation age is lowered to 110 years in the second and third situations.

DISCUSSION

If the question is, "Will well-defined relaxations of nonadjacency constraints make them less binding in mathematical programming formulations?" The answer is yes. The number of age classes necessary to cover a map and meet the weaker constraints is fewer. It is tempting to conjecture that the number of age classes as stated mathematically goes from $5*(E/R) - 1$ to $4*(E/R) - 1$. There is even a plus, since we can prohibit same-period to same-period violations and still schedule an area using $4*(E/R) - 1$ age classes.

If a further question is, "Can either strict compliance or relaxed compliance be imposed while finding some optimal harvest schedule?" The answer is no. We can find feasible schedules quickly using sequential or backtracking map coloring algorithms (Welsh and Powell 1967, Nijenhuis and Wilf 1978), but the number of age classes used may be many more than the minimum. We can also generate hundreds of these schedules (colorings) and calculate their present net values or potential production. Further research may show that such a method will have a reasonable expectation of stumbling on a "near-optimal" schedule, especially if there is not much variability in worth or productive capacity within the compartment. Such a "fast" coloring algorithm can be included in a heuristic computer-based harvest scheduler that allows some level of noncompliance with nonadjacency restrictions, and permits evenflow targets to be included.

We believe that a more pertinent question is, "Why bother with juxtapositional constraints in the first place?" On one hand, we know of no naturally occurring landscape mosaic that looks anything like a collection of small evenaged timber stands in a regulated condition whose spatial arrangement adheres to temporal nonadjacency

constraints. Franklin (1988) questions whether the establishment of geometrically arranged monocultures promotes species diversity of either flora or fauna. But on the other hand, nature does not imitate the biological effects of a 1000-acre clear cut, not even with "stand replacement" natural fires. Some middle ground is surely better than either.

We advocate that work be done to establish ecosystem-based diversity measures for horizontal and vertical spatial arrangement of flora and fauna. Qualitative and quantitative estimates of changes in diversity over time can be made using geographic information systems coupled to ecosystem models. Prescriptions for optimal resource use can be approached in an iterative manner and modeled over varying time spans (Müller-Merbach 1975). A "fast coloring" algorithm can be used to generate possible spatial arrangements (if we insist on a stand-by-stand approach). The diversity indices of these prescriptions can be checked against the levels desired for those measures. This approach cannot guarantee maximum present net value or maximum physical production or any other optimal measure, but as more iterations are performed more poor solutions are eliminated.

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Modeling and Integrating Environmental and Public Concerns in Ponderosa Pine Forest Resource Management: Moderator's Comments

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The papers in this session relate to the two great changes in public land management over the last 25 years. First, managers must now inform and involve the public, or an array of "publics" in their planning. And second, they must carefully evaluate as many as possible of the environmental consequences of their management actions (or lack of actions). These two changes have revolutionized public land management, and they have made the managers' job a good deal more difficult.

Addressing environmental concerns is not easy. The environmental impact assessment process that comes from NEPA and other legislation is far from perfect. At times the process can be slow, confusing, costly and needlessly bureaucratic. At times the process may not adequately identify the impacts or their magnitudes. Still, the fact that at least some portion of mankind's activities are now routinely screened ahead of time for their environmental impact is a monumentally important step forward.

There is still a great deal of work to do before these impact assessments in ponderosa pine forests can be comprehensive, accurate and reasonably useful. There are many species we do not yet know enough about. Our understanding of ecological, hydrologic and other processes is often far more crude than we would like. Still, the manager today has far more models, simulators, etc. with which to predict some of these impacts than were dreamed of just a few decades ago.

Even if we assume that the land manager and his or her staff can accurately identify all of the impacts of a proposed management scheme, the manager can no longer simply proceed to make his decisions guided only by his actual (or hoped for) budget. The public must be informed and consulted. This country is a democracy, and that fact cannot be ignored in public land management.

Everyone (almost) seems to agree that public involvement is a "good thing". Public involvement is not at all easy to gather or assess, and the public may be far from easy to satisfy. First, there is not one public with a unified voice. There are many groups with different aims and interests. They may have different levels of understanding of ecological processes. They may demand different and contradictory things. Second, how does a manager get good public input? How can he ensure a fair and representative cross section of public opinion, rather than hearing only from the few highly organized, skillful or most vocal special interest groups. How can he get this input with a minimum outlay of his meager resources? Third, what do you do with public input onece you have it? What is the best way to forge compromises between competing demands? And, what if the public (with little training and experience) wants management that the trained and experienced land manager thinks is unwise? The manager in the end must make his decisions, even if they are buffeted about by politics, policies, and budgets. The public may not always be right. However, the public and the manager cannot remain at odds indefinitely. Sooner or later, either the manager will educate the public to come around to his point of view, or our political process will slowly work its will on our government bureaucracies and the manager will be out of a job.

It is easy to see, then, why public involvement and environmental impact assessment are such fertile fields for research efforts. Ponderosa pine land management is no exception.

Multiresource Management and Public Involvement[1]

Ace H. Peterson and Ryna P. Peterson[2]

Abstract.--This paper presents a historical sketch of public-agency conflicts and interactions within the multiresource management decisions and programs of Ponderosa Pine Forests. These conflicts and their resolution are presented from the public perspective of effective methodology to reach such resolution and provide a viable partnership in multiresource management.

INTRODUCTION

The context of this paper explores the concepts wherein forest resource management conflicts with public perception of those managements, public involvement and the interaction needed to resolve those conflicts. The purpose and scope of these resolution processes are based upon the experience of the presenters, and the recognized perspective that these experiences reflect and are similar to those experienced by other interested publics in attempts to interact with land management agencies, agency personnel, and practices.

The presentation from the Public's (layman's) perspective, explains the styles and techniques used to effectively interact within multiresource management. Within this context, the public's involvement is explored dealing with both the frustrations of interacting within the processes and the ultimate achievement of reasonable resolution wherein integration of public input into multiresource management resolves conflicts and reaches issue settlement.

HISTORICAL

The concept of public involvement (other than commodity users) in forest resource management, is in reality that of recent time frame. With minor exception, public participation resided with those entities commercial or legislative in nature. Public or citizen involvement did indeed have such notable champions as John Muir, Theodore Roosevelt and Aldo Leopold; however, the voice of the citizen was rarely heard in dealings of the forest management agencies on the forest lands nationwide.

Forest wide planning and entity involvement for and within National Forest resources evolved through several distinct phases. In this presentation only the major Acts which govern resource management including timber, will be addressed. Acts, Congressional in nature, some of quite some age, are still relevant in today's environment of interelationships between the resource manager and the citizen public.

In 1876, Congress took two bold steps, modest by today's standards, which started the process leading to other Acts, which today govern public lands, resources, and management. These steps also started the long process leading to Acts guaranteeing citizen participation. The first, introduced by Representative Greenbury L. Fort (Oregon Law Review, volume 64, 1985) of Illinois, stated intent "for the preservation of forests of the National domain ajacent to the sources of navigable rivers and streams of the United States." The second was an appropriation of two thousand dollars for the Commissioner of Agriculture to employ some man of approved attainments for preparation of a wide ranging report on forestry matters. In 1886, Congress established the Division of Forestry. This was followed in 1891 by the Creative Act, passed to set apart public lands and timber. The Transfer Act of 1907 set aside lands for what became National Forests. It is interesting to note, that this time period became the start of the earliest recorded public involvement with the citizen public attempting to direct Forest policy for other than commercial or speculative reasons.

The next era of major resource Acts was the 1960's with the advent of the 1960 Multiple

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Use Sustained Yield Act. During the middle 60's, the publics were able to exert pressure on Congress and the resource agencies for more of a voice into the decision making process with minor success. Such organizations as Sierra Club, Wilderness Society, Izzac Walton League and the National Wildlife Federation with their affiliates became leading forces in laying the major groundwork towards true public involvement and resource management change during this era. Public consciousness was awakening. In 1969 the NEPA (National Environmental Protection Act) was passed and signed into law. NEPA finally spelled out the legal process and guidelines wherein the publics could be fully involved within management and policy decision making processes. The agencies drafted regulations and policies directing the rules of engagement, and the public needed another whole decade to gear up, digest, and interpret the rights of public involvement.

Other important Acts were passed bolstering the needs and rights of public involvement. The Resource Protection Act of 1972 (RPA), National Forest Management Act (NFMA) in 1976, Federal Land Management Policy Act (FLPMA), the Endangered Species Act, Clean Water and Clean Air Acts, gave the public the voice and tools to further interact within the multiresource management spectrum. However, NEPA passed in 1969, provided the public the basis to reference and implement the various Acts and regulations of resource management. While the light had appeared at the end of the tunnel, progress towards full and equitable participation has still been a slow process burdened by the inertia of resistance to change within the land management agencies and at times the whims of Congressional interference.

PUBLIC CONCERN, EDUCATION, INTERACTION AND PERCEPTIONS OF MULTIRESOURCE MANAGEMENT

This portion of the narrative gives an overview of the public's efforts to come to grips with the management and decisions affecting public land management and the resources on or in those lands. Without a lengthy step-by-step analysis, a picture can still be attained of public concern and frustration in dealing and interacting within the many laws, regulations and policies of public land management. These efforts were hampered, restricted or circumvented by lack of knowledge of these laws, regulations, and policies on the part of the public, and, in some instances, hampered by ideological conflicts between the public and the land management agency, or Congress.

Even though John Muir had awakened public interest in their natural resources early in the 1900's, the major thrust of public involvement and concern evolved in the 1960's. Perhaps for the first time in history, major portions of a populace had the time, education, interest, and resources to pursue conservation goals and ideals. Citing Muir, Leopold, Rachel Carson, Thoreau, and others, the citizen public entered the arena for participation in deciding the future of their public lands and resources. The public marched directly into a wall of bureaucratic resistance and bounced off into a maze of legalistic misdirection and confusion.

Until the era of the 60's, the public perception of public resource management was one of implied trust in the management agencies and their policies. Indeed, one agency's motto, "Caring for the Land and Serving People" (United States Forest Service), appeared directed toward securing this implied trust. Simply stated, the public perception was one of viewing those who managed the public resources as wise and benevolent managers, keeping the lands and resources for the good of the public, and the Nation.

In time, the public became informed and educated in resource matters, and more voices raised questions of concern. Individuals and organizations became interested in agency decisions and policies affecting lands, waters, wildlife, and other resources. Public interaction raised serious questions regarding uses of public resources, questioned seemingly biased management decisions, and attempted to correct the problems the public had seen or perceived. The citizen public had realized by various means and methods that current management of the times was indeed biased in direction and lacking in meeting all the needs or the public's interest. A lesson quickly learned was when an agency or its personnel spoke of "our land, our trees, our resources," "our" meant the agency's possession and not the public's. Education and participation within the processes and interaction by whatever level taught the public that commodity interests were indeed prioritized and public interests of wildlife, recreation, and esthetic resources were of lower priority whose values were often skewed or biased (constrained was not the buzz word yet) in the broad picture of resource values.

By the 1980's, the public had grasped a firm handle on the how, where, when, and why of resource planning, legal rights of interaction, and intervention in such planning if necessary. The crux of all multiresource management including timber, and especially forest issues and conflicts, would arise in a document entitled the Land Management Plan (LMP).

NFMA (National Forest Management Act), signed into law on October 22, 1976, directed the Secretary of Agriculture to prepare and promulgate regulations for Forest Service planning modeled on guidelines within the Act. NFMA required all contracts, permits, and other legal instruments allowing use of a National Forest, to conform to that Forest's management plan. Finally, the Act required the Forest Service to "attempt" (italiics added) to complete the new plans by the end of fiscal year 1985 (Oregon Law Review,

Volume 64, 1985). Now the conflicts became focused as to forest management between the Forest Service and the public entities. The Land Management Plans, more so than possibly any other agency action, focused attention on the complexities and ambiguities of dealing with an agency, and the realm of legalistic, interpretative, and negotiative actions within multiresource planning implementation.

PUBLIC CONFLICTS IN INTERACTING WITHIN MULTIRESOURCE PLANNING

The public, through previous interactions in timber sales, mineral entry, grazing allocations, and wilderness plans, had to some extent forced the Forest Service and other agencies out of their protective boxes. The agency's reaction, on the other hand, was similar to an analogy of removing Jello from a container with a pin; lots of movement and some progress, but with a lot of frustration. Much depended upon regional or local forest service personnel as to the amount of progress made. However, on the whole, the agency resisted concrete gains by the public within what the agency interpreted as "their" eminent domain.

The public's attempts to interact within the scope of multiresource management and planning was stonewalled by agency interpretation and methodology. Interpretation of words, phrases, definitions, and procedures varied extremely as to who was interpretating these, agency or public, and in many instances varied from forest to forest. Even the very Congressional Acts, NEPA, FLPMA, NFMA, were interpreted differently as to intent and meaning by both agency, public, and, at times, the Courts.

Methods used by the agency involving, or not involving the publics also created confusion and conflict. The use of minimum notice was intended to satisfy the NEPA requirements of public participation. Notification of hearings, or planning appeared in miniscule wording within the legal section of newspapers next to corporate documents, tax records, repossessions, and the like, or were published in journals located in municipalities far removed from the interested populace. Of course the fine line was these items of notification were published in the National Register, which is not one of the most common household subscriptions. Mailing addresses while purported to be computer updated and complete seldom notified all the interested public participants. In fact, this type of misdirection resembled nothing so much as a portion of a novel, wherein the hero, Arthur by name, awakes to find a highway bypass proceeding toward his house. When Arthur inquired or could we say intervened, he was told that proper notification had been given as required by law. Quoting in paraphrase what transpired was this: "the legal notice had been posted in the basement of the appropriate department, and because the lights did not work, a flashlight was needed along with a ladder for the missing stairs; in the bottom drawer of a filing cabinet in a disused lavatory with a sign on the door reading "beware of leopard" (The Hitchhikers Guide to the Galaxy, Douglas Adams, 1980). An appropriate example of minimum notice.

Legal definitions and notification of appropriate time frames for response to or intervening in agency decisions became another example of bureaucratic misdirection. Deadlines were hidden in phrases pertaining to Forest Service regulations and never printed in their entirety, pursuant to CFR something or other with all the legal numbers and subsections. The publics often found themselves outside the process because of missing or misinterpretating a response deadline.

The methodology of determining resource values created increasing conflicts with the publics, especially those interested in wildlife, recreation, and esthetic values. Conflicts arose over allocation of resource dollars and management direction pertaining to recreational visitor days (RVD), wildlife-fish user days (WUFD). Just what determined a WUFD? Why were not all WUFDs equal? How long was an RVD? Should WUFDs and RVDs be different in value? Where was the parity between these entities within forests, forest to forest, region to region, or states? Foreplan, the computer model used to generate land management plan data, allocations and values, along with other input, became questioned as to validity accounting for more issue conflicts.

Many more conflicts are both conceived and perceived by the agency's inability to articulate to the public the reasons for, and the processes of multiresource planning and implementation. The public moved by a need or a concern, requires information which can be understood and followed within the process, providing viable input to those plans and or projects of interest.

CONFLICT RESOLUTION IN MULTIRESOURCE MANAGEMENT

The conflicts affecting multiresource management, whether real or perceived by agency or public still exist to a greater or lesser degree. While progress has been made, considerable distance has yet to be covered in totally resolving these conflicts. The public entities feel a need to be involved in the management of public lands and resources. The Forest Service and other agencies are viewed by the public as their resource managers, while the public fulfills the role of stockholder within the management spectrum.

In order to adequately and equitably manage not only timber, in this case Ponderosa Pine, but all resources in a multiresource mode, both

the public and the managing agency must reach agreement through communication and cooperation. Both the publics and the agencies speak of a working partnership, one of equitable relationships toward implementing multiresource decisions. This is only possible when both entities understand the other, and cooperate within the framework of such understanding and cooperation. The era of simple implied trust is past history. However, a mutual trust within the scope of partnership goals and objectives can, and must become reality.

Within this scope of cooperative partnership reside two avenues, along with associated responsibility, which if used, will serve to implement the goals and objectives of true multiresource management. One of these avenues directs the managing agencies, the other directs the interested publics. One theme must exist, in that these are parallel avenues rather than divergent paths.

Agency/Public Interaction

The guidelines discussed and listed in this portion of the text are intended to provide a system wherein the public can interact with the agencies, and relate to the data required to provide viable input. As discussed earlier, there is a shared responsibility in dealing with multiresource management.

A. Before an agency, such as the Forest Service, can distribute information and program intent, there must be a direction from the public which accomplishes two main purposes. The first is a declared intent by a citizen or organization to become involved. This should take the form of a letter to the office of the agency involved at whatever levels are deemed necessary. Preferably send this letter to the Supervisor's office of the forest or districts to be interacted with. Secondly, the agency must know where to contact the person who expresses this interest. If more than one person is to be involved, specify along with the above information this person's area of responsibility or interest.

The agency, upon receipt of this notification, must place this information in the appropriate files or programs for mailing use along with needed updates. This data must also be desiminated, using the Forest Service as an example, to the districts and to the Regional office.

B. Even though the participant should be receiving adequate notice from the agency on plans, decisions, or projects, it is the participant's responsibility to make themselves aware of such actions via newspaper, newsletter or other personal communication.

The agency has a similar responsibility. Beware of fulfilling only the minimum requirements of the law. This is what those data files of interested publics are for, proper notification via radio, television news, up front in the proper newspapers, and by letter to those persons whose names are in the computer or other files. Too much notification is much better than little or none at all. It is a lot easier to notify than have a project stopped via appeal intervention.

C. The participant needs to keep themselves aware of dates, times and deadlines. The agency needs to make sure these are clear, concise and understandable.

D. Know the agency personnel and citizen representatives that are to be worked with on any program or project. It is far easier to establish a viable working relationship with someone who is known visually as well as by title or signature. Get further acquainted via meetings with each other, rather than just at public hearings.

E. Respect the opposition, if indeed this is how the one views the other. The golden rule, treat as you would be treated, applies here. The agency personnel are not just titles or signatures, they are people with the same human traits as the citizen public. These persons have spent years of their lives learning the resource they manage, plus the education process of college or university.

On the other hand, the agencies need to realize the citizen public have become very well educated in resource matters and the legal processes regarding interaction. Too many times agency personnel tend to fall back on "professional" attitude without listening to or accepting as "value" the public input. The public in many regards are just as professional as the person wearing the agency uniform. Remember, both are after the same end product, and a fresh outside perspective can yield very productive results.

F. Know the regulations and pertinent laws of public involvement. This applies to both parties. It is amazing how many agency personnel are ignorant, at times, in this area. The agency, as their job, should be very knowledgeable in this item. The participant should have available a copy of the CFR code, NEPA, and FLPMA references as a minimum. The agency should take the lead in resolving conflict by supplying these to the interested public when they receive notification of such interest. Appropriate sections of the agency handbook dealing with regulations and techniques of resource management are recommended.

The laws and regulations need to be used by both parties in the intent for which these

were created. Which is to provide clear direction for participation and management. Unfortunately, both parties tend to use these punatively, which in many instances starts conflict where none may have existed.

G. To enable both the agency and the citizen public to communicate, there must either be a common language or an understanding of the language the agency uses in preparing plans or documents. Far too often, either by intent or forgetfulness, what is spoken or written by the agency comes out in acronym form. RVD, AVM, MMBF, WUFD, ROD, CFR, basal area, DBH, shelterwood method, intermediate cut, these and more are commonly used, and the public has no idea what is being discussed. Just as the public needs to learn all the jargon to communicate, the agency would be better advised to speak "layman" and to prepare documents in plain English so both are discussing the same thing. Glossaries of terms should be made available in places and times other than the back of an LMP or EIS.

H. It is not always clear to the public just what the need for a particular project may be, or why the project is designed in a particular manner. The "how, why, what, and where" need to be fully understood by the public, at the earliest point of time in the process.

I. One of the major points of conflict which arise via the project scheduling or implementation, is the "why" factor. Projects are being drafted by the agencies with, at times, no definite purpose in mind, other than the public's perception of cutting trees. Each project should be spelled out up front. The need for, and what the project is to accomplish should be understood clearly by the public and agency alike.

J. The publics need to work within the system without using the ultimate tools of intervention, which are appeals to work within that same system. If the partnership idea is to be feasible, each must strive to accomplish the plan or project for the mutual benefit of the resource or resources involved. If as a last resort, mutual agreement cannot be reached, the agency must not take "personally" the public's use of appeal or even litigation. The public must also be realistic in the agency's prerogative to forward items of impasse onto their appropriate place of decision.

In conclusion, the points of solution while apparently simple, are just now being defined and addressed within the land management agencies. The Forest Service has implemented programs to instruct their personnel in how and when to involve the citizen public. Other agencies either are, or should be initiating similar programs. We, the public and the agency, are irretrievably linked in managing the resources of our public lands. Each needs to more fully understand the role of the other in this spectrum. Multiresource management must consider the human factor as an integral part of this form of resource management; not in the social or user context alone, but rather as a dynamic team interacting together to benefit all resources including mankind for this and succeeding generations. Perhaps Aldo Leopold said it best when he expressed this philosophy, "we shall never achieve harmony with the land, but the important thing is to strive to achieve" (Sand County Almanac 1949). This quote also speaks true for conflict resolution within multiresource management.

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Multiresource Forest Management with EZ-IMPACT Simulation Models[1]

R. W. Behan[2]

ABSTRACT

The central features of multiresource forest management are a system view of the forest, and the foreknowledge of systemic responses to proposed management activities.

A forest system simulation model is therefore indispensable in the practice of multiresource management. The importance of simulation models, however, is underestimated and underemphasized, particularly in professional forestry curricula, which at least appear to be obsessed with quantified optimization models instead.

The construction and use of simulation models should be important parts of undergraduate education in multiresource management, and are essential in field practice.

A proprietary software product, EZ-IMPACT^{tm}, offers an economical means of constructing judgement-based, situation-specific computer simulation models of forest systems and the social environment in which they are managed.

INTRODUCTION

EZ-IMPACT^{tm} is a proprietary computer program developed and marketed by Biosocial Decision Systems in College Station, Texas (Biosocial Decision Systems, 1987). It provides an economical means of constructing a judgement-based, situation-specific computer simulation model of a forest system and the social context of constituent groups in which it is managed. Various prospective management alternatives can be simulated, to project the impacts on the entire forest system; and the alternatives can be tested against the value-agendas of the constituent groups, as well. On-site, constituency-based multiresource management is made possible, with an off-the-shelf package of software.

In the professional, scientific literature we don't often, shouldn't often, find endorsements for proprietary products. For the practice of on-the-ground multiresource forest mangement, however, the EZ-IMPACT^{tm} software is unique and indispensable; until a competing and superior product is marketed, the implied endorsement can't be avoided. (Hereafter I will abbreviate the software package "EZI.")

EZI isn't purported to be better than everything else: at the moment, as far as I know, there simply isn't anything else. Meanwhile, the product offers multiresource forest managers a capability they can scarcely do without.

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SIMULATION MODELS AND MULTIRESOURCE FOREST MANAGEMENT

The central feature of multiresource forest management, which sets it apart from the traditional single-resource, sustained yield paradigm of professional forestry, is a system view of the forest, and a foreknowledge of the systemic responses of the forest to proposed management perturbations.

What is the response of wildlife habitat, for example, or of scenic amenities to the expansion of a road network, or to alternative timber harvesting quantities or techniques? Or what happens to timber growth and harvest in response to various alternative regimes of big game management, or various potential configurations of fire management or wilderness designations?

Only a simulation model can provide prior insights into such systemic responses. And only a computer simulation model can hold hundreds of system components in memory simultaneously, to trace thousands of interactions in any sensible period of time.

As the concept and techniques of multiresource forest management continue to be developed, however, I believe the importance of simulation models is being severely underestimated and underemphasized.

Instead, we are fascinated by, and we are producing a voluminous literature about the role of optimizing models--linear programming applications in particular--in multiresource management. I believe the fascination has become obsesssive.

Certainly we are teaching the use of LP models with vigor and verve: textbooks and curricula abound with Z-functions, constraints, coefficients, and the Right Hand Side. Students whale away for hours in the computer lab, running endless iterations, looking for the feasibility polygon's optimal but elusive corner point, in all that hyperspace.

I believe this obsession with optimality is leading our students, and the profession of forestry, in the wrong direction. In a subtle and beguiling way, with little notice and wholly without critical scrutiny, it is creating a professional context or environment of technical determinism, even technical perfectionism. It is perpetuating the notion that professional land management is preeminently a technical or scientific undertaking. It discounts and discourages the appreciation for, the confidence in, and the development and exercise of sound managerial judgement.

The difficulty here lies not in the shortcomings of the LP algorithm. Nothing in my experience can top it for ingenuity, possibly excepting the G.I. can opener, the Derry-slotted steerable parachute, and thermal-gradient energy generation. I applaud Professor Dantzig for working it out, and his students and successors for developing and disseminating the elegant variations.

The problem lies in our extension of LP solutions into problem levels, magnitudes, or strata where they are wholly inappropriate.

LP optimization models work very well when objectives can be realistically and legitimately quantified, and when the problem is fundamentally simple--adjusting an oil refinery's output of several products, for example--but the possible choices are infinite or nearly so. These might be termed "tactical" problems.

Tactical problems arise in forestry, beyond doubt. When they do, LP solutions might well be in order. But often in forestry, particularly in multiresource forestry, we are dealing with higher-level problems--we could call them "strategic" problems--in which the objectives transcend quantification.

If objectives cannot be realisitically and legitimately quantified, LP optimization techniques are useless. This point is rarely overlooked in the teaching of optimization, to the credit of the authors and the adopters of the current textbooks. I believe, however, we overlook it or discount it extremely heavily in a far more profound way: when we decide to emphasize optimization so obsessively in undergraduate curricula in the first place, and continue uncritically to do so.

In my judgement, strategic problems are far more common than we realize, particularly if we define them simply as those that transcend quantification.

Multiresource forest management itself, it seems to me, is fundamentally

a strategic problem. We all agree that most multiresource values cannot be realistically or legitimately quantified, but we fail to act out our convictions. First we use, decently enough, market data to quantify timber and forage values. Then we make some heroic and ingenious efforts to quantify some more, and finally we simply assign or impute values to the rest, for the construction of a hypothetical objective function: thus is made possible the teaching of LP principles.

This is an exercise almost literally in fantasy: but even if all the output values could be legitimately quantified, real-life multiresource management objectives would still not be completely defined.

Management objectives, multiresource or otherwise, characteristically are complex, multiple, often amorphous in the extreme. In the private sector, such things as market share, labor retention, public good will, the long term continuity of the enterprise, and so on and on, are all critically important elements in strategic objectives.

Not at all infrequently do some elements of a multiple, complex, amorphous objective--that is to say a real one--conflict directly with others. Consider the conflict between "customer satisfaction" and "net revenue" for example. Both are essential to the welfare of a firm, and, arguably, they are direct, zero-sum trades.

In the public sector, the difficulties multiply. Objectives here also contain complex, multiple, amorphous elements, but there is a further barrier to quantification not often encountered in the private sector. Because there is a plurality of "owners" of public forests, there is almost always a plurality of prospective "objectives," and almost never consensus. If objectives cannot be agreed upon, they certainly cannot be quantified.

Optimization models, in management situations as complex as multiresource forestry, are intriguing curiosities and devilishly clever, but they depend utterly upon the impossible. In the whole arena of management responsibilities, nothing is more difficult than the specification of strategic objectives; there is good reason to believe it can't be done.

Aaron Wildavsky, Charles Lindblom, and Herbert Simon have been making this argument for years, and I believe their arguments apply to multiresource forest management. In Wildavsky's words, we don't know what we want until we know what we can get; in Lindblom's, the best we can do is to muddle through; in Simon's, we have to settle for "satisficing," not maximizing.

All this is such common knowledge among students of management science there's no need to elaborate it, nor to cite the references. And we can arrive empirically where Wildavksy, Lindblom, and Simon take us theoretically: how often have private forest owners told their forest managers simply and exclusively to maximize PNV? Have American people <u>ever</u> said that to the managers of public forests?

No, real objectives in multiresource forest management cannot well be specified, much less quantified, but we carefully and successfully deny the irrefutable. We continue to instill (and demand) competence, among forestry students, in the use of optimization models--demonstrably useless tools, except at the tactical level, for the practice of multiresource management.

Witness the most conspicuous attempt to use optimization techniques where they are hopelessly inappropriate--the sorry episode of national forest planning. After spending 13 years and 16% of its total management budget for the entire national forest system, and using an LP model seeking to mazimize PNV, the U.S. Forest Service has satisfied essentially no one. As I suggested above, there is disagreement over the <u>objectives</u> for which the national forests are managed, but no one, to my knowledge, has been hawking the maximization of present net value. (There may be, indeed, a consensus of opposition, and certainly one of indifference.)

Professor K. Norman Johnson, the architect of FORPLAN, is as sound a critic as anyone I know who has addressed this matter in print. The National Forest Management Act was much more strongly focussed, Johnson argues, on "...the assurance of protection of the forest environment during all actions" than on economic efficiency. (Johnson, 1987.) Sound multiresource forest management, if I may paraphrase Johnson, was more important than maximizing PNV.

The Forest Service selected Johnson's own creation, FORPLAN, as its optimizing model. Nevertheless, he went on to say this:

Selection of an optimization model for forest planning has limited the ability to consider environmental effects in detail in forest planning modeling. I do not believe that an optimization model such as FORPLAN is required by the NFMA. An equally strong argument can be made for models that emphasized the simulation of environmental effects from road building and timber harvesting...

The obsession with optimization is widespread, apparently, and simulation models are underemphasized, insufficiently exploited.

There is one final reason I find the emphasis on optimization unfortunate in the development and in the teaching of multiresource forest management. Optimizing models can only tell us, as we test the production of various alternate output mixes, what happens accordingly to the "objective function": how well we are maximizing PNV, or minimizing costs, or some other strictly determined, quantified objective. Optimizing models do not and cannot tell us what happens <u>in the forest system</u> as the product mix is varied. That is the critical element in multiresource forest management, and only simulation models can do it.

BUILDING SIMULATION MODELS WITH EZ-IMPACT^{tm}

Some General Comments

Far more than we do, I believe, we should be teaching the construction and use of simulation models, and touch on optimization as an interesting exercise in the pursuit of idealized perfection, an exercise of occasional but slight applied utility, and one that is avoidable--largely, justifiably, and inevitably.

There are at least two elements inherent in building computer simulators of forest systems that bear on their reliability and the fidelity with which they reflect reality: the character of the data inputs, and the nature of the algorithm, or algorithms, that manipulate the data.

The most sophisticated simulation models use research-generated data and uniquely constructed algorithms appropriate for that body of knowledge. An example is ECOSIM, a model of high reliablity and fidelity developed in the ponderosa pine forests of the Southwest. The problem with this class of models is high cost: ECOSIM took about 15 years and $5 million to produce.

At the other extreme are models that can use judgement-generated data (even "guesses") about the nature of the system to be modelled, and apply generic algorithms. EZI models fall in this category, and the huge advantage here is low cost: given familiarity with the software, an EZI model can be built in a few hours. I would estimate a very useful model could be produced, iteratively, and by thoughtful, knowledgeable resource managers, in a week.

This is not the place to engage in a pointless debate about the superiority of one class of models over another. Clearly, reliability and fidelity on one hand, and cost on the other, are tradeoffs. For most prospective multiresource managers, I presume, cost and time are stringent constraints: there may be no realistic option to a judgement-based, generic-algorithm simulation model. In these circumstances, obviously, EZI models become irresistibly attractive.

Building an EZI model of a forest system is enormously valuable even if the manager never uses it for testing prospective management activities. It is an intellectually demanding job, and having done a few, I can verify there is no better way of coming to understand the workings of the forest system at hand.

First, the manager is forced to indentify the critical variables in the forest system, and then to describe the relationship of each variable to all the others. Thinking all this through imparts a knowledge of the forest system, and an understanding of its behavior that can be gained in no other way. That is why I think we should be spending far more time in undergraduate forestry curricula building and running forest simulation models.

Details: the Construction and Use of EZ-IMPACT^{tm} Models

The first step in using the EZI software is to name the model. This also designates a data-file that will be stored by the computer. In the example to follow, we will track the ENCHFOR3 model--the third version of a model I

have built for the manifestly hypothetical "Enchanted Forest."

When EZI simulates a management alternative, it does so with a fixed run of 20 iterations. The next task is to distribute those twenty iterations over an appropriate period of time--for how long do you want to observe the system's behavior? First you choose a unit of time--a year, a month, an hour, a minute. Then you choose the time period--a number of units between 5 and 60. Having chosen, say, "minute" and "60", you have designed a model with a "life span" of 60 minutes, and the iterations will take place at 3 minute intervals. In a ten-year model, on the other hand, the iterations will take place every six months. Not much tree growth, certainly, takes place in three minutes, so these choices are not trivial. (ENCHFOR3's time interval is 5 years.)

Next you specify the month and year in which you want the simulations to begin. (ENCHFOR3 fired up in January of 1989.)

The next step may be the most critical. The important variables for your model must be identified and described, and a unit of measure for each must be selected. The software does not use the these directly, but forcing model builders to specify measurement units also forces them to sharpen their thinking about the variables. Suppose, for example, "wilderness" is an important variable. What about wilderness is important? Is it the total area, the new area dedicated each year, or the use that is accommodated annually? Appropriate measurement units would be acres, acres/year, and visitor-days/year, respectively.

Next, for each variable, the "maximum feasible increase," the "expected change," and the "external impacts" all are specified, which does a number of important things.

By expressing a maximum feasible increase for each variable, measuring the subsequent behavior of each can be "normalized," and expressed in every case in terms of "percent of maximum." Expressing the maximum also imputes an initial value: if a variable can double over the time-span of the model, its initial value must be 50% of its maximum.

The "expected change" for each variable constitutes the existing management regime; every system has to start somewhere, so EZI is always dealing at the margin.

The "external impact," expressed as a percentage of the expected change, accounts for variables acting from "outside" the model. A certain percentage of acreage burned, for example, will be caused spontaneously by lightning ignition, while the rest is accounted for in controlled ignition; if the model represents the manager's control-arena, spontaneous ignition is an "external impact."

Figure 1 displays the variables in ENCHFOR3. Only variables 1-8 will be active in the simulations to follow, in order to keep this example model simple--64 cells instead of 400. Variables 9-20 are entered with no values, simply to display some other variables that might be included in a working model. (EZ-IMPACT will handle up to 39 variables.)

Note that virtually any kind of variable, even "fuzzy" variables, are accommodated in EZI. I believe this is one of its major virtues: we can be as comprehensive and as realistic as we choose. The only limit is the imagination of the modeller, and the legitimacy of the variable.

Foresters have long struggled with scenic beauty, for example. We have some research-based "scenic beauty estimators" used in ECOSIM and elsewhere (Brown and Daniels, 1984). I have wondered for a long time if we could measure scenic beauty indirectly in the negative, in terms of complaints about its destruction. One of the dummy variables in the model, number 16, is NEGBEAUT, accordingly, and I will appreciate restraint with respect to the obvious play on words.

The selection of variables is deceptively easy, and it is deceptively easy, I found, to choose atrocious ones. DPDRKWDS--Deep Dark Woods--my first attempt at EZI modelling, displayed dozens of them. Done without the advantage of a rough decision rule on selecting variables, Deep Dark Woods turned out to be a useless monster.

My rough decision rule, fashioned much later, is this: include in the model the <u>investment</u> actions and

Figure 1. Variables and trends for ENCHFOR3 Multiresource Model.

EZ-IMPACT
Multiresource Management Model III for the Enchanted Forest

No.	Variable Name	Variable Description	Unit of Measure	Maximum Increase (%)	Expected Change (%)	External Impact (% Exp.)
1	TBRGRWTH	timber growth	mbf/year	100.0	50.0	0.0
2	THN'VEST	thinning investment	$M/year	200.0	75.0	50.0
3	TBRHRVST	timber harvest	mbf/year	200.0	100.0	60.0
4	DR&ELKPD	deer & elk prduction	animals/year	100.0	25.0	0.0
5	D&EHRVST	deer,elk harvested	animals/year	100.0	50.0	75.0
6	WLDFIRES	acreage of wildfires	acres/year	1000.0	100.0	75.0
7	WLDRNSS	designated wlderness	thousands acres	100.0	50.0	50.0
8	ROADCON	road construction	miles/year	1000.0	25.0	50.0
9	FORPROD	forage production	tons/acre/year	0.0	0.0	0.0
10	GRAZING	forage consumption	AUM's per year	0.0	0.0	0.0
11	H2OYIELD	water yield	acre ft./year	0.0	0.0	0.0
12	PRESBURN	acreage,prscrb.burns	acres/year	0.0	0.0	0.0
13	DEVREC	developed recreation	visitor days/yr.	0.0	0.0	0.0
14	DISPREC	dispersed recreation	visitor days/yr.	0.0	0.0	0.0
15	NEGBEAUT	ngtve scenic beauty	complaints/yr.	0.0	0.0	0.0
16	INVSTREC	invst.rec.developmts	$/year	0.0	0.0	0.0
17	REVCOUNT	revenue to counties	$/year	0.0	0.0	0.0
18	RNGINVST	investmt,range mgt.	$/year	0.0	0.0	0.0
19	CLEARCUT	acres clrcut per yr.	acres/year	0.0	0.0	0.0
20	PARTCUT	ac.partial cut/yr.	acres/year	0.0	0.0	0.0

Time period is 5 years, beginning 1/ 1989.

activities available to the manager--thinning, road building, fire suppression, harvesting, and other things managers can do to the system--and the biophysical and social variables that will be impacted, accordingly--growth rates, visitation rates, acreage burned, sediment loading, etc. What you want the model to accomplish, it should be apparent (but it wasn't to me initially), should dictate the relevant variables. If you want to project the impacts on the system of prospective management decisions, include the system variables and the decision variables, and leave everything else out. (A parsimonious list of variables is very much to be desired, as we shall see.) I'm ashamed to suggest how long it took me to learn this.

In the next step, managers will come to see their forest as they've never seen it before. They will indeed see the forest, sense the forest, as a system, because the relationship of each variable to all the others must be specified, with four parameters. The "type" of impact can be either long-term and cumulative, or short-term and proportional. (There are some unambiguous definitions of these terms to be applied.) The impact's direction must be specified: is the impacted variable driven up or down? What is the strength of the impact--strong, moderate, or weak? (Finer distinctions are possible, but might be specious.) Finally, a constraint on the impact can be inserted, if it occurs only when the impacting variable is rising or falling.

This is the step in which you are literally building the model. If there is hard information at hand to guide your specification of the relationships, by all means use it. (A thorough literature review prior to constructing the model, while not necessary, would raise the fidelity of the model, of course--and its cost.) If not, you must rely on judgement--your's and others', which can be augmented effectively if a Delphi process is used. The ways in which data input can be improved are many, each carrying a different price tag.

Foresters who know their forest system and its behavior as well as they should, or as well as they think, can breeze through this exercise. Very few will, in fact, breeze--a measure of our ignorance of how forests really work.

Figure 2 shows the "original model" of ENCHFOR3; it includes all the parameters except the "strength of relationship." (The omission will be explained shortly.)

It is now time to joust directly

Figure 2. Type of impact, direction, and constraint parameters in the ENCHFOR3 model.

EZ-IMPACT

PROJECT: ENCHFOR3
Original Model Multiresource Management Model III for the Enchanted Forest

No. Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 TBRGRWTH	.	+L	-S C	-S C	-S C	-L	.	.	.	.	.	.	.	.	.
2 THN'VEST	.	.	+S C	.	.	-S C	.	.	.	.	.	.	.	.	.
3 TBRHRVST	+S C	.	.	.	.	-S Up	-S C	.	.	.	.	.	.	.	.
4 DR&ELKPD	-L	+S C	+S C	.	-S C	+S C	.	.	.	.	.	.	.	.	.
5 D&EHRVST	-L	+S C	+S C	+S C	.	.	.	+L	.	.	.	.	.	.	.
6 WLDFIRES	+L	-S C	+S C	.	+S C	.	+S C	-L	.	.	.	.	.	.	.
7 WLDRNSS	.	.	-S C	.	.	+S C	.	-S C	.	.	.	.	.	.	.
8 ROADCON	.	.	+L	.	.	+S C	.	.	.	.	.	.	.	.	.
9 FORPROD	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
10 GRAZING	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
11 H2OYIELD	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12 PRESBURN	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
13 DEVREC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
14 DISPREC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
15 NEGBEAUT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
16 INVSTREC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
17 REVCOUNT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
18 RNGINVST	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
19 CLEARCUT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
20 PARTCUT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

with your computer, which expects you to be rational, consistent, and bright. If you have built a good model, and if you have included no logical contradictions, physically impossible feedback loops, or other dumb features, the model should gallop through the specified time period and produce the "expected changes," shouldn't it? Your model should be able to display your current management regime producing the expected results.

It probably won't. We have built the model piece by piece, relationship by relationship, and we simply can't keep all the pieces in our minds simultaneously. The computer can, of course, and does: that is the collossal advantage of computer models, and we should not be offended when the computer asserts this peculiar superiority. But it certainly will, and we will certainly be offended.

This will happen in EZI's "Refinement" process. The user's manual steers us through the debugging process, and when the model can hit the "expected change" values within plus-or-minus 4%, it is declared, by both the computer and the triumphant modeller (with damp palms and a relieved grin), to be "refined." (The software adjusts the "strength" parameter to accomplish this, which is one reason why an initial three-way discrimination is probably sufficient.)

Figure 3 shows the 8 active variables "refined" to fall within the plus-or-minus 4% standard. (This is a screen-print generated with the MSDOS GRAPHICS command.) Figure 4 shows the "unrefined model," and displays the initial "strength of impact" parameters. Figure 5 displays the "refined model," in which the "strength" parameters have been adjusted. (These are printed out directly by EZI.)

We can check the refined model by running a simulation of the existing management regime, an "experiment" called "EXPECTED." The results are available on screen as a bar chart (Figure 6) or a line-graph (not illustrated), or printed in tabular form (Figure 7). For each variable, the "difference from expected values" is zero, as we would expect.

Now we have a workable model in which, by virtue of its ability to "predict" the expected values we initially specified, we have a fair

Figure 3. "Successful Refinement" screen, showing simulations falling within 4% of expected values.

** REFINEMENT IN PROGRESS **
ITERATION 4 OF 10

DEVIATION FROM EXPECTED VALUE (% of Max. Units)

TBRGRWTH	0.01	THN'VEST -	0.26	TBRHRVST -	3.60	DR&ELKPD	1.28
D&EHRVST	2.51	WLDFIRES	1.74	WLDRNSS -	1.95	ROADCON	0.99
FORPROD -	0.01	GRAZING -	0.01	H2OYIELD -	0.01	PRESBURN -	0.01
DEVREC -	0.01	DISPREC -	0.01	NEGBEAUT -	0.01	INVSTREC -	0.01
REVCOUNT -	0.01	RNGINVST -	0.01	CLEARCUT -	0.01	PARTCUT -	0.01

Figure 4. "Unrefined" (assigned) strength-of-impact parameters.

EZ-IMPACT

Multiresource Management Model III for the Enchanted Forest

PROJECT: ENCHFOR3
Unrefined Model

No.	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	TBRGRWTH	.	0.0300	-2.0000	-1.0000	-1.0000	-0.0300	.	.	.	.	.	.	.	.	.
2	THN'VEST	.	.	2.0000	.	.	-1.0000	.	.	.	.	.	.	.	.	.
3	TBRHRVST	1.0000	.	.	.	.	-3.0000	-2.0000	.	.	.	.	.	.	.	.
4	DR&ELKPD	-0.0200	2.0000	1.0000	.	-2.0000	2.0000	.	.	.	.	.	.	.	.	.
5	D&EHRVST	-0.0200	2.0000	1.0000	2.0000	.	.	.	0.0100	.	.	.	.	.	.	.
6	WLDFIRES	0.0100	-2.0000	1.0000	.	1.0000	.	1.0000	-0.0100	.	.	.	.	.	.	.
7	WLDRNSS	.	.	-3.0000	.	.	2.0000	.	-3.0000	.	.	.	.	.	.	.
8	ROADCON	.	.	0.0200	.	.	2.0000	.	.	.	.	.	.	.	.	.
9	FORPROD	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
10	GRAZING	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
11	H2OYIELD	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12	PRESBURN	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
13	DEVREC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
14	DISPREC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
15	NEGBEAUT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
16	INVSTREC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
17	REVCOUNT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
18	RNGINVST	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
19	CLEARCUT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
20	PARTCUT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Figure 5. "Refined" strength-of-impact values, adjusted so that simulated expected values fall within 4% of assigned expected values.

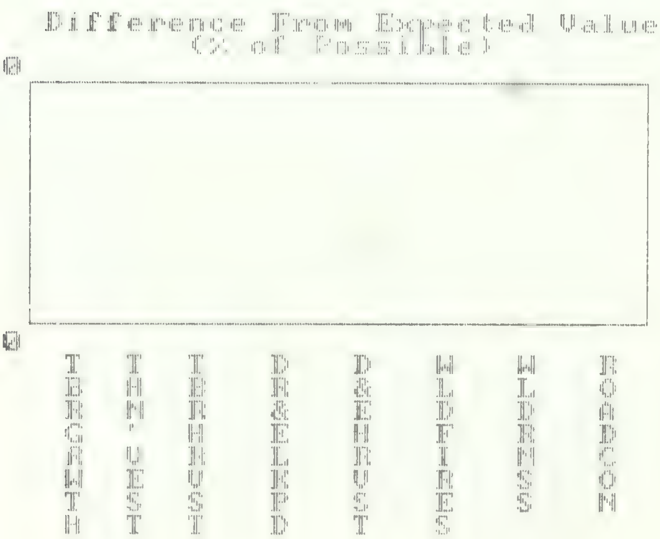
EZ-IMPACT

Multiresource Management Model III for the Enchanted Forest

PROJECT: ENCHFOR3
Refined Model

No.	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	TBRGRWTH	.	0.1414	-0.7029	-0.6876	-0.2122	-0.0064	.	.	.	.	.	.	.	.	.
2	THN'VEST	.	.	1.6468	.	.	-1.1139	.	.	.	.	.	.	.	.	.
3	TBRHRVST	2.3492	.	.	.	.	-0.7394	-0.8513	.	.	.	.	.	.	.	.
4	DR&ELKPD	-0.0162	2.4655	0.8575	.	-1.6224	2.4655	.	.	.	.	.	.	.	.	.
5	D&EHRVST	-0.0282	1.4191	0.6582	1.5343	.	.	.	0.0071	.	.	.	.	.	.	.
6	WLDFIRES	0.0078	-2.5743	0.9701	.	0.7769	.	0.6362	-0.0129	.	.	.	.	.	.	.
7	WLDRNSS	.	.	-0.8889	.	.	6.7501	.	-0.8889	.	.	.	.	.	.	.
8	ROADCON	.	.	0.0031	.	.	0.3109	.	.	.	.	.	.	.	.	.
9	FORPROD	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
10	GRAZING	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
11	H2OYIELD	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12	PRESBURN	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
13	DEVREC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
14	DISPREC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
15	NEGBEAUT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
16	INVSTREC	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
17	REVCOUNT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
18	RNGINVST	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
19	CLEARCUT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
20	PARTCUT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Figure 6. Bar-chart for "EXPECTED" experiment. Refined model generates "zero" deviation from expected values if the simulations fall within 4%.



degree of confidence. The value of building the model, thinking through the important variables in our forest system and how they interact with one another, has been substantial. We have been forced to adopt and to experience a "systems view" in order to get this far, and that much alone, I believe, justifies the exercise.

But now the practice of multiresource forest management can begin. We can design different management alternatives (EZI calls them "experiments") and see what would happen to the system if they were implemented. Suppose we doubled the timber harvest? We might name this "experiment" CLEARCUT, multiply our initial "expected change" value for the TBRHRVST variable by two, and run that simulation.

The impacts on all the other variables are displayed in Figure 8, measured in terms of "Difference from Expected Change." Thus we can compare the proposed alternative to our current management regime. (Again, the data can be printed in tabular form as well.)

Figure 7. Tabular results of running the EXPECTED experiment. Differences from "expected values" are zero, as in the bar-chart in Figure 6.

EZ-IMPACT

Multiresource Management Model III for the Enchanted Forest

EXPERIMENT: EXPECTED
Time period is 5 years, beginning 1/ 1989.

Variable No.	Variable	Initial Value (% of Max.)	Final Value (% of Max.)	Expected Val (% of Max.)	Difference from Initial Value (%)	Difference from Initial Value (% of Possible)	Difference from Expected Val (%)	Difference from Expected Val (% of Possible)
1	TBRGRWTH	50.0	75.4	75.4	50.7	50.7	0.0	0.0
2	THN'VEST	33.3	60.3	60.3	80.9	40.5	0.0	0.0
3	TBRHRVST	33.3	65.0	65.0	94.9	47.5	0.0	0.0
4	DR&ELKPD	50.0	63.0	63.0	25.9	25.9	0.0	0.0
5	D&EHRVST	50.0	77.4	77.4	54.8	54.8	0.0	0.0
6	WLDFIRES	9.1	15.8	15.8	73.6	7.4	0.0	0.0
7	WLDRNSS	50.0	67.1	67.1	34.3	34.3	0.0	0.0
8	ROADCON	9.1	12.1	12.1	32.6	3.3	0.0	0.0
9	FORPROD	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
10	GRAZING	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
11	H2OYIELD	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
12	PRESBURN	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
13	DEVREC	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
14	DISPREC	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
15	NEGBEAUT	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
16	INVSTREC	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
17	REVCOUNT	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
18	RNGINVST	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
19	CLEARCUT	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0
20	PARTCUT	100.0	100.0	100.0	- 0.0	- 0.0	0.0	0.0

Other bar charts can display the results of the CLEARCUT alternative in terms of "Final Values" for all the variables, or in terms of "Difference from Initial Values."

Figure 9 shows the results of NOCUT, in which timber harvest has been halted completely. Figure 10 displays the consequences of ALLWILD, which designates every potential acre as wilderness. NOWILD, the results of which appear in Figure 11, is a timber-beast's dream: timber harvesting and road construction have been driven to their maxima. And BLOWUP, displayed in Figure 12, describes the situation in which the maximum acreage of wildfire impact has been sustained.

Figure 8. Results of simulating the CLEARCUT experiment. Variable #3, TBRHRVST, has been assigned its maximum value of 200%.

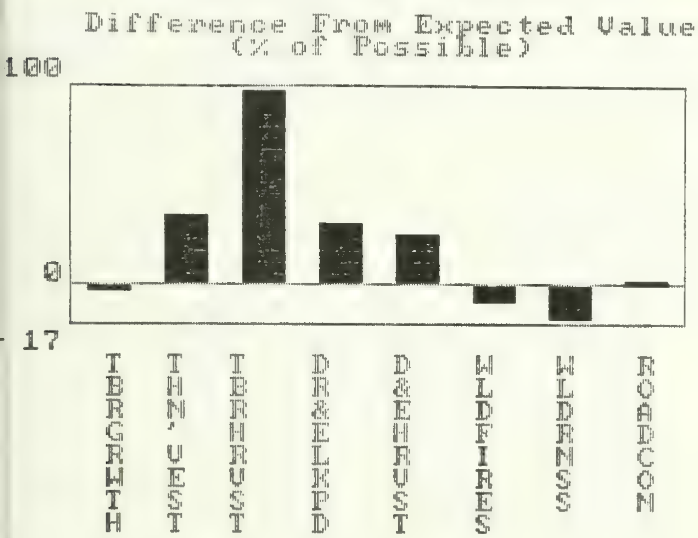
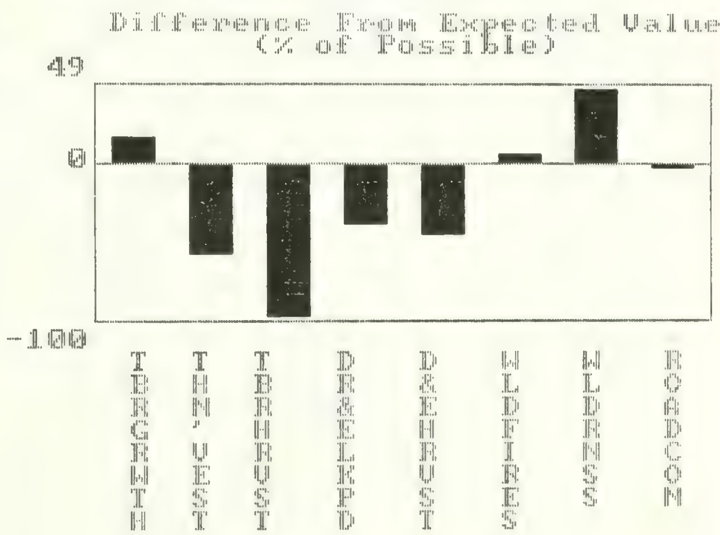


Figure 9. Results of simulating the NOCUT experiment. Variable #3, TBRHRVST, has been decreased by 100%.



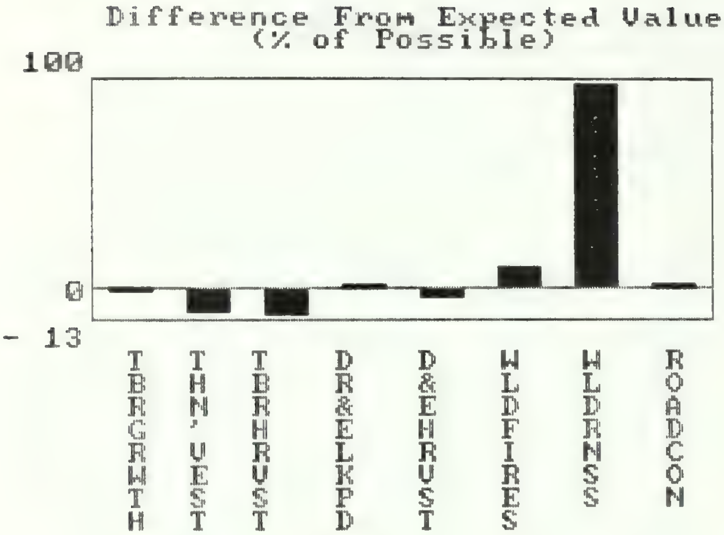


Figure 10. Results of simulating the ALLWILD experiment. Variable #7, WLDRNSS, has been increased by 100%.

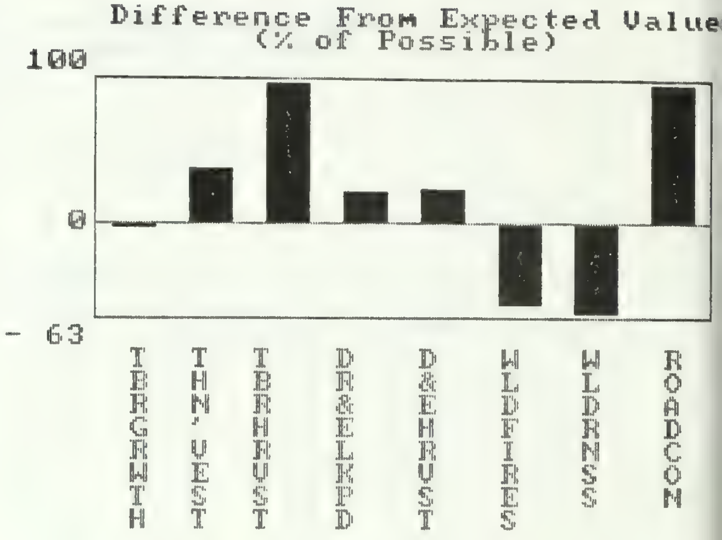


Figure 11. Results of simulating the NOWILD experiment. Variables #3 and #8, TBRHRVST and ROADCON, respectively, have been taken to their maxima, 200% and 1,000%.

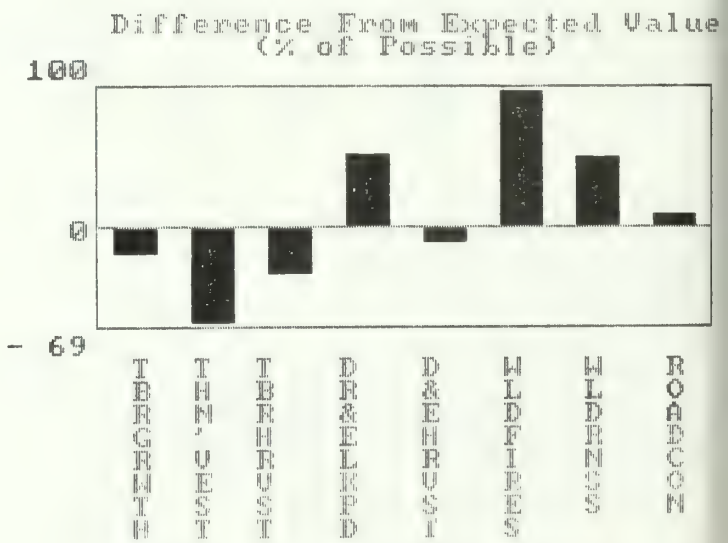


Figure 12. Results of simulating the BLOWUP experiment. Variable #6, WLDFIRES, has assumed its maximum value, an increase of 1,000%.

Can a manager finally make a choice, using an EZI simulator (or a simulator built some other way), without resorting to an optimizing model as well (or instead)? The affirmative answer to that question is self evident; but in my view, the exclusive use of a simulation model is not only possible, but preferable. (In this case of strategic, not tactical, decisions, that is.)

In comparing the EZI alternatives, or in constructing more and different possibilities in a search for one to apply on the ground, the manager inescapably confronts the expressed <u>and</u> tacit objectives of his management unit. The manager will choose a course of action, one will seem "better" than the others, because it will appear, consciously or otherwise, to further those objectives more than the rejected alternatives. The objectives can be rich, complex, plural, ambiguous, certainly unquantified, even unspecified: in short, the use of simulation models <u>without</u> or <u>instead</u> of an optimization model accommodates reality to a gratifying degree. (There are dangers: the exercise of managerial judgement is difficult, and there are no guarantees. But if managerial judgement cannot be taught, the Harvard Business School is a fraud.)

Optimizers, we have seen, work well on small problems, where indeed the objective can be realistically and legitimately quantified. The final decision is made by the manager, of course, not the model, but optimizers challenge only a very primitive mental capability, the process of comparison. Numbers are compared, and one PNV is seen to be larger. The course of action that generates that PNV is thus chosen. This mental activity is precisely equal to the capability of the computer, which is limited to making comparisons, too: it can only distinguish the presence from the absence of an electrical current.

Relying exclusively on a simulator--which I believe is inescapable for

larger, more difficult problems in which objectives can not be realistically or legitimately quantified--calls instead for higher mental capabilities. The manager is called upon to integrate information, not just to compare it, and to make a judgement based on that integration. All a manager needs in order to proceed comfortably is the conviction that his mind--capable of such integration--is indeed superior to the comparison-limited capability of a computer.

So far, only the simulation features of EZI have been exploited, and we have seen the manager operating alone, isolated from the social context in which forestry is practiced. The manager has integrated some information about objectives, which certainly reflects social preferences, but he has avoided direct social interaction.

EZI has another invaluable and ingenious capability to foster such interaction. It can be used to model the social context as well as the biophysical forest. EZI can identify clientele groups, order their preferences or objectives for each of the modelled variables, and test their resulting levels of satisfaction for any or all of the "experiments," the proposed management alternatives.

My ENCHFOR3 model, implicitly simulating national forest land in the vicinity of Flagstaff, Arizona, contains three clientele groups: the Stone Container Corporation, whose pulp and solid-wood mills collectively are the largest consumer of timber; the Arizona Wildlife Federation; and the Wilderness Society, which has a regional office in Phoenix. (EZI can accommodate up to 15 such groups in a model.) I have also included the multiresource manager as an interested party, to exhibit some important behavior of the EZI software.

Figure 13, which the program prints out, displays the various groups and their respective preferences for the trajectories of each of the modelled variables, which can range from "Up Max" to "Don't Care" to "Down Max." (The dummy variables are assigned the default

Figure 13. Objectives for each variable in the model presumed appropriate for each affected interest group.

EZ-IMPACT

Multiresource Management Model III for the Enchanted Forest

PROJECT: ENCHFOR3

OBJECTIVES

		Group			
No.	Variable	STONECC	AZWLDLF	WILDSOC	MRMGR
1	TBRGRWTH	Up Max 100%	Don't Care	Don't Care	Up 50%
2	THN'VEST	Up Max 200%	Not Down	Not Up	Up 75%
3	TBRHRVST	Not Down	Not Up	Not Up	Up 100%
4	DR&ELKPD	Don't Care	Up Max 100%	No Change	Up 25%
5	D&EHRVST	Don't Care	Not Down	Down 50%	Up 50%
6	WLDFIRES	Don't Care	No Change	Don't Care	Up 100%
7	WLDRNSS	Down 100%	Not Down	Up Max 100%	Up 50%
8	ROADCON	Down 100%	Not Down	Down 100%	Up 25%
9	FORPROD	No Change	No Change	No Change	No Change
10	GRAZING	No Change	No Change	No Change	No Change
11	H2OYIELD	No Change	No Change	No Change	No Change
12	PRESBURN	No Change	No Change	No Change	No Change
13	DEVREC	No Change	No Change	No Change	No Change
14	DISPREC	No Change	No Change	No Change	No Change
15	NEGBEAUT	No Change	No Change	No Change	No Change
16	INVSTREC	No Change	No Change	No Change	No Change
17	REVCOUNT	No Change	No Change	No Change	No Change
18	RNGINVST	No Change	No Change	No Change	No Change
19	CLEARCUT	No Change	No Change	No Change	No Change
20	PARTCUT	No Change	No Change	No Change	No Change

EZ-IMPACT

Multiresource Management Model III for the Enchanted Forest

PROJECT: ENCHFOR3
EXPERIMENT: EXPECTED

Satisfaction of Group Objectives *

Group	Total Satisfaction (% of Max.)**	Highest Dissatisfaction (%)	Highest Dissatisfaction Variables	Dif. From Initial Val (%)	Objective
STONECC	92	67	WLDRNSS	34.3	Down 100%
AZWLDLF	95	47	TBRHRVST	94.9	Not Up
WILDSOC	87	70	D&EHRVST	54.8	Down 50%
MRMGR	99	13	WLDFIRES	73.6	Up 100%

* Computed using normalized (% of Max.) units.
** Maximum excludes variables assigned 'Don't Care'.

Figure 14. Satisfaction levels of the various interest groups with the EXPECTED experiment, the current management regime.

value "No Change," which is treated with indifference in the simulations.)

Figure 14 compares the various groups' reaction to the current management pattern, the EXPECTED "experiment." Fairly high levels of total satisfaction are indicated for each group, but high levels of dissatisfaction are shown for single variables, reflecting the strong partisanship of the individual groups.

The multiresource manager is virtually 100% satisfied. This "experiment" is, after all, his existing management plan. (His slight dissatisfaction with the WLDFIRES variable is simply a numerical response occasioned by the model-refinement process.)

Similar printouts can be made for each of the "experiments," or the aggregated satisfaction levels can be compared for the entire range of alternatives. Figure 15 does this; we can see, in the right hand column, that one group or another is 100% dissatisfied with each of the extreme alternatives--a conclusion that is intuitively sound.

The existing state of affairs, represented by the EXPECTED "experiment," appears to be the best choice according to any of the decision criteria. It maximizes the total weighted satisfaction, and is the least hurtful to all the groups or to any one group, simultaneously. Recalling that the multiresource manager himself (and exclusively) was 100% satisfied with this alternative, perhaps we have displayed a brilliant professional forester performing at his best.

(More likely we have displayed a cagey and fortunate model builder, who designed the array of "expected values" to be as "reasonable" as he could.)

The social-context features of EZI can be exploited a number of ways. A forest management team can "sense" its constituency by role-playing the client groups, for example. Or a formal workshop with representatives from the various groups can fill in the blanks.

Perhaps the most effective (and, unfortunately, expensive) approach is a joint workshop of managers and clients alike. Such a workshop can produce the forest simulator as well as the constituency simulator, and jointly build the inventory of management alternatives. As the simulations are run and discussed, as new alternatives are constructed and tested, consensus comes within reach.

A promising example of this approach was conducted on the Flathead

EZ-IMPACT

Multiresource Management Model III for the Enchanted Forest

Project: ENCHFOR3

Satisfaction of Objectives by Policy Experiment

Experiment	Total Weighted Min. Sat. All Groups (% of Max.)	Total Weighted Sat. All Groups (% of Max.)	Highest Dissatisfaction Any One Group (%)
EXPECTED	[84.4]*	[92.9]**	[69.9]***
CLEARCUT	79.8	91.1	100.0
NOCUT	79.5	89.3	100.0
ALLWILD	83.1	92.3	100.0
NOWILD	72.6	87.6	100.0
BLOWUP	75.9	89.6	100.0

* MAXIMIN Solution: Policy maximizes total weighted minimum satisfaction (i.e., policy is least hurtful to all groups).

** MAXIMAX Solution: Policy maximizes total weighted satisfaction (i.e., policy provides the most benefits to all groups).

*** MINIMAX Solution: Policy minimizes dissatisfaction for any one group (i.e., policy is least hurtful to any one group).

Figure 15. Comparison of the 5 alternate management options ("experiments") in terms of aggregate satisfaction levels.

National Forest, using an earlier version of the EZI software. (For a description written by two of the participants, see Stout and Brannon, 1989.)

A final feature of EZI is contained in a "Set Priorities" subroutine. Both the variables and the relationships between the variables can be assessed as to their judged importance, ranked, and displayed. This feature is primarily valuable for establishing research priorities. It is an intelligent element in the software, but multiresource managers will find it useful less often than the simulation modelling capability.

EZ-IMPACT^{tm} is a brilliant creation and a compelling product, I believe. Used with care--and with imagination and skill--it can further the application of on-the-ground multiresource management uniquely, immediately, and effectively.

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Recreation and Esthetics Management in Southwestern Ponderosa Pine: Assessing Research Needs[1]

Merton T. Richards and Terry C. Daniel[2]

Abstract--Explicit relationships need to be specified between management activities for the production of commodities, and the provision of recreation and esthetics opportunities in southwestern ponderosa pine forests. Models for recreation experience opportunities and forest scenic beauty are reviewed and a combined "expert judgement" model is proposed. Research needs for such a model are assessed.

INTRODUCTION

The recreational use of forestlands in the southwestern United States is increasing rapidly and will continue on this trend for the foreseeable future. Several factors contribute to this trend, some of which are occurring nationally while some are especially prevalent in the Southwest.

Population growth in Arizona and New Mexico has been dramatic for nearly twenty years. Although recent demographic projections indicate some slowing in the rate of growth of the southwestern population the trends are still upward. In addition, people from major population centers in Texas, southern Nevada, and southern California continue to pursue leisure activities in the forested mountains of Arizona and New Mexico in growing numbers.

Rapid technological innovation in leisure oriented equipment and modes of transportation contribute to growth in forest recreation nationally, and the Southwest in particular. Relatively inexpensive, comfortable, easy to use, and readily available equipment for camping, fishing, hunting, skiing, and hiking pervades the marketplace. Motorhomes, small, but rugged four-wheel drive trucks, boats, and all-terrain vehicles including "mountain" bicycles complement the new equipment in meeting a demand grounded in a popular cultural ethic. Outdoor activities are believed to contribute to peoples' mental and physical well-being and to be socially desireable.

Social and cultural evolution in the United States has resulted in a predominantly urban population that is culturally diverse and somewhat older, on average, than in previous decades. In general, people today enjoy greater economic prosperity and have more options for leisure time, including retirement, than ever before. Among other effects, the "season of use" of forestlands for recreation has expanded to a year long basis. Other effects of social and cultural change, however, are less benign. A greater variety in leisure activity preferences and values, more urban oriented social behavior patterns, and a bigger range in the ages of recreation participants provide complications for forest management.

The growing numbers and diversity of recreation users of forestlands guarantees social and managerial conflicts, both between recreation and other forest uses, and among recreation uses. Even on forestlands presumably devoted exclusively to recreational use, e.g., federal and state parklands, national recreation areas, and designated wilderness areas, certain other uses are provided for, ranging from livestock grazing to spiritual, scientific, and educational purposes. Most forestlands, including private lands, are explicitly devoted to multiple uses.

It is generally assumed that commodity uses of forests are competitive with recreational (amenity) uses, and that commodity production will denigrate recreational opportunities. While

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this is often the case, it is not universally true. For one thing, some levels of forest management conducted for the production of commodities can improve recreation opportunities such as better road access, improved wildlife habitat, or increased scenic vistas associated with the removal of forest trees. For another, some levels of recreational activity on forest lands can degrade the potential for commodity production, such as an increased fire hazard, negative impacts on livestock production, or restrictions on off-forest water uses to preserve on-forest water based recreational opportunities.

Within the spectrum of recreational uses of forestlands, many activities are competitive. Activities that depend on solitude cannot take place, obviously, at the same time and place as those recreation pursuits involving large groups of people or that are dependant on motorized vehicles. Hunting and fishing activities typically are inconsistent, at least in the same time and space, with non-consumptive wildlife appreciation.

The problem, in the context of forestland management, is one of accommodation and amelioration. It is necessary to define appropriate trade-offs between and among various forest land uses. To define trade-offs, explicit physical and social relationships for the various uses need to be expressed. It would be useful to model, both quantitatively and qualitatively, response functions that express changes in specific forest recreation opportunities as a function of changes in physical and biological forest characteristics.

This paper will describe and define the forest recreation experience, the relationship of recreation opportunities to common forest management activities, and propose an approach to modeling relationships between recreational and other uses of forestlands. Consideration will be given to the esthetic quality of forestlands, both in its own right and as an important contributor to many forest recreation activities. Research needs will also be defined.

The geographic focus of this paper is on the southwestern United States with particular reference to ponderosa pine forests. This forest type is prominent in Arizona and New Mexico and provides a substantial amount of forest recreational opportunities. Most of the arguments and conclusions made in this paper can be applied to the mixed conifer and pinyon juniper forest types that also occur in this region.

THE WILDLAND RECREATION EXPERIENCE

Wildland recreation is a special form of leisure behavior not only because it takes place out-of-doors, but, because it depends upon a natural, or "wildland," environment. Particular environmental conditions, or settings are crucial to the fulfillment of wildland recreation goals, because the wildland recreationist seeks meaningful and satisfying experiences rather than simply engagement in activities.

Importantly, forest recreation takes place in settings that result from forest management actions of one form or another, whether the objective is recreation opportunity, wildlife habitat, or timber harvest, among others. It is unreasonable to assume that any forest management activity will result in appropriate recreation settings, without regard to the way the elements of a setting influence recreation demand and visitor satisfaction. In the following paragraphs, a more detailed examination of settings, recreation demand and experiences, and their relationship to various forest management actions is presented.

Given that different recreation experiences depend upon particular wildland settings, any of a large number of recreation opportunities might be provided through manipulation of the features of a particular wildland area. It is essential for management purposes to define a limited but, reasonable number of desirable experience opportunities. Two considerations are helpful in this regard. Within a particular forest ecotype opportunities for experiences are obviously limited to settings found in that ecotype. Furthermore, no one management entity, including public agencies, is obligated to provide every possible opportunity. The Recreation Opportunity Spectrum (Driver and Brown 1978) provides a methodological framework for assessing and selecting an appropriate mix of wildland recreation opportunities.

The Recreation Opportunity Spectrum (ROS) provides a systematic means to inventory wildland units in terms of recreation opportunity settings, gives a framework for defining management actions appropriate to recreation objectives, and permits the monitoring of impacts due to management over time (Clark and Stankey 1979). The ROS is based on the idea that recreators' pursuits of certain activities in particular places is actually a revelation of their demand for experiences that are satisfying and that may give long term psychological benefits. The focus on experiences rather than activities is central to the ROS concept and it provides a perspective for recreation management that differs from the recent past (Driver and Brown 1978). The ROS model presents a spectrum of experience opportunity classes that relate the range of desirable recreation experiences to an array of possible wildland settings. A key

advantage of the model for managers is the flexibility in the structure of opportunity settings. Setting structure is composed of three components: an ecological component (consisting of biological and physical factors), a social component (the number of people in the setting at one time and their kinds of social interactions), and a managerial component (kinds of facilities provided and the degree of regulation of recreators). Forestland managers can choose to offer any or all possible settings by altering these components. Obviously, the ecological component relates directly to management of wildland resources for non-recreational purposes.

Meeting recreation demand requires forest settings that are consistent with desired experiences. Inconsistent forest settings may arise from management activities that place competing recreational uses in conflict or that introduce incompatible non-recreational uses. When any or all three of the ROS components (ecological, social, managerial) of an opportunity setting do not contribute to a given experience type an inconsistency exists. Whether the inconsistency is important or not is a managerial determination that should be guided by agency or firm goals for recreational use. Therefore, assessing the impacts of management actions on recreational use of forestlands requires a clear understanding of the management entity's goals and responsibilities.

The ponderosa pine forests of the southwestern United States offer settings potentially appropriate for a broad range of recreation experiences. The particular experiences recreators demand is, to a degree, dependent upon economic and demographic characteristics of the southwestern U.S. population. The outstanding feature of this population, especially in Arizona, is growth. Population growth is occurring across most income classes and age groups, but middle income earners and young to middle age groups are favored. It appears that these groups will exert an increasing demand on wildland resources for leisure pursuits. In particular, the ponderosa pine forestlands will continue to be highly valued recreational settings due to relatively easy access, generally high scenic quality, moderate climate, and spacious atmosphere.

The land ownership pattern in the Southwest is dominated by federal acreage, and, the total acreage of land available for wildland recreation opportunities is still very extensive relative to the regional population. This places relatively large, federally managed, wildland recreation opportunity areas in close proximity to rapidly growing urban centers. The result is an increasing number of recreation visits of short duration (4 hours to 3 days) to federal land locations.

In summary, forestland recreation opportunities in the Southwest will continue to occur on federal lands. This, in turn, means that the supply of opportunities is, at least conceptually, very large. However, specific recreational opportunities associated with ponderosa pine forests are constrained by certain factors.

Southwestern ponderosa pine forests are predominantly managed by the U.S. Forest Service. Obviously, from the foregoing, agency goals coupled with ecological characteristics common to the forest type limit the spectrum of opportunity settings that will be provided. For example, the U. S. Forest Service should provide opportunity settings for experiences that are unavailable under private sector or other public sector management.

RECREATION MANAGEMENT IMPACTS FOLLOWING OVERSTORY MANIPULATION

In general, management impacts on recreation can be either positive or negative and they may result from both non-recreational and recreational activities. The focus here will be on impacts due to non-recreational management activities. The incidence of management impacts on recreation occurs in the consistency of the recreation opportunity settings. Negative impacts create inconsistencies while positive impacts have the opposite effect.

The impacts of timber management activities on recreation primarily affect visibility and access. Roads built for timber management purposes frequently enhance recreational opportunities. For more primitive experiences, however, roads may be a distraction. In any case, timber management roads are not typically located or designed primarily for recreational experiences. As a result, negative impacts on visibility and cognition often occur. For example, more than 75 percent of respondents to a recreation study in the Mogollon Rim area of Arizona wanted no more forest roads (Richards and others 1977). Their concern was for esthetics and wildlife.

Timber harvesting activities can create significant visual impacts due to the scale of operations. Visual impacts of roads take two forms: the scenic quality of the road corridor, as viewed from the road, and the visibility of the road as a more distant landscape feature. The initial, disruptive appearance of harvested areas usually seen from roads or other travel ways, is exacerbated by soil disturbance and slash. On the other hand, small scale or selective harvest activities can serve to improve the scenic quality of forest areas. Far views,

showing incongruent vegetation patterns or road scars provide negative visual impacts. Timber harvest activities may also impact air and water quality, damaging esthetic values and degrading swimming and fishing opportunities Livestock production in ponderosa pine forests takes place primarily in the summer and early fall seasons. While this is also the period of heaviest recreational use, the negative impacts of livestock production on recreation are mostly indirect involving fixed facilities (fences, buildings, tanks) and induced vegetative changes. On the other hand, the presence of livestock in the forest in common dispersed patterns may contribute a romantic sense of southwestern tradition to wildland recreation experiences.

Vegetative changes induced by livestock grazing can adversely affect scenic values. Severe overgrazing and trampling can lead to soil erosion with resulting visual blight, especially in riparian areas. Alterations in plant species composition, primarily of larger shrubs and forbs can reduce the scenic value of forest lands (Brown and Daniel 1984).

The effects of fire on recreation in ponderosa pine forests are primarily esthetic. Coupled with increasing public awareness of the value of fire in forest ecosystems, recent research shows that negative impacts on scenic quality from forest fires are very short term (Anderson and others 1982). In fact, prescribed burning may reduce slash from timber harvesting or naturally accumulating downed wood and forest litter, improving scenic values.

Taylor and Daniel (1984) show that light burning may improve scenic beauty of forest landscapes over time (their data ranged over five years). Severe burning, however, had a negative impact on scenic value. They also assessed the impact on recreation acceptability by respondents' preferred activity. Campers and picnickers found fire impacts more unacceptable than those interested in nature study.

Efforts to increase water yield in ponderosa pine forests, or to control water run-off can have negative effects on recreation. Physical facilities such as dams and roads associated with water development or control projects can provide visual impacts. Water bodies impounded by these facilities may enhance the landscape view and usually provide for water based recreation. Such impoundments, however, can result in the loss of wild and scenic rivers, and river or stream based fishing opportunities.

For the most part, management of wildland resources for wildlife complements recreation management objectives. The visual quality of forest scenes is generally improved by diversity in resource conditions, especially vegetation. This is consistent with the provision of wildlife habitat for a broad array of forest fauna.

Particular recreation experiences may be precluded in locations where wildlife are sensitive to human contact or to certain recreational activities. Some forms of off-road vehicle use are incompatible with wildlife requirements as are some forms of fishing. Threatened or endangered species merit special consideration in this regard. These impacts on recreation are mitigated to some degree by the value many recreators hold for knowing that wildlife is protected (Witter and others 1978; Richards and others 1979).

Insects and diseases occurring in forest areas bring negative impacts on recreators by defoliating, killing, or grossly deforming vegetation. Less often, insects may create impacts when they act as pests to recreators. However, they serve a useful function as a food source for wildlife and as agents of decomposition of residues and waste matter, thereby creating more attractive and healthy recreation settings.

MODELING RECREATION AND ESTHETICS

It has been a common assumption that forest recreational and esthetic resources are not amenable to systematic, much less quantitative, analysis. The assumption seems rooted in the notion that recreation and esthetic experiences are dependent upon highly subjective attitudinal and emotional responses. However, commonalities in recreational choices (as evidenced by crowding of popular sites) and consistency in expressions of esthetic quality have frequently been identified. As a result, systematic and even quantitative assessments of the quality of forest recreational and esthetic experiences have been accomplished.

Wildland recreation and esthetic appreciation interests are only two of an extensive array of resources and uses that must be provided by limited forestlands. An understanding of the relationships between recreational, esthetic and other important uses is essential to effective forest management. To the extent that these relationships can be defined explicitly, and where possible, quantitatively, better management decisions for forestland uses can be made. In this paper the intent is to employ the Recreation Opportunity Spectrum concept in a proposed model to systematically define the relationship between characteristics of forest environments and the opportunities for recreational experiences that visitors seek. Further, models of forest scenic beauty will be reviewed and related to the proposed recreation model.

The ROS is typically defined as a functional linkage between recreational experience opportunity classes and a variety of environmental settings, or forest conditions. An opportunity class is a subjectively defined segment of the opportunity spectrum. It defines a class of recreational experiences that could be enjoyed in a particular environmental setting. The setting, in turn, varies according to its ecological, social, and managerial attributes. Therefore, changes in the environmental setting will result in changes in recreation experience opportunities.

Recreation Models

Recreation models have been developed for a wide range of purposes, from simulating visitor distribution across proposed sites (Cesario 1975), to forecasting use (Stynes 1983), and simulating dynamics of use over time (Levine and Lodwick 1983), to numerous economic demand models (Ward and Loomis 1986; Sorg and others 1984; Walsh and others 1989). The ROS is a model of recreation supply, at least as it has been described in this paper. While models describing the use of, or demand for, recreation are fairly common, models of recreation supply are less so, probably because of a general assumption that wildland recreation largely takes place in environments unmodified by humans, and, therefore, the appropriate supply is fixed. As Clark and Stankey (1979) point out, this is too simplistic. The ROS, in fact, can be used as an analytical tool to evaluate the impact on the supply of recreational opportunities due to human use of forest environments. The simulation of forest environments affected by management actions should include changes in the spectrum of recreational opportunities (supply) defined by the ROS.

Implementation of the ROS has been done by the U.S. Forest Service. In their approach, they have defined six recreation experience opportunity classes. Further, they provide descriptive statements for each class that characterize the setting (or forest environment) and the kinds of experience provided by each class. However, these characterizations are general and remain somewhat vague.

The Forest Service has developed specific criteria to be used to delineate classes according to the ROS characterizations. The criteria specific to the ecological component of an environmental setting are remoteness, measured in miles from roads or other vehicle access, size in acres, and evidence of humans as noted by man-made features. The social component of a setting is assessed by a user density criterion, measured in the frequency of encounters with other parties. The criteria used to define the managerial component are the degree of regimentation and how noticeable it is.

These criteria permit relatively unambiguous standards and management guidelines to be developed for a forestland area. ROS classes can be delineated and mapped for the area, and management prescriptions for both recreational use and for other forest resource uses can be developed by ROS land class.

The ROS model should permit a rational and optimal allocation of land to a mixture of appropriate recreational uses as well as other land uses. That is, for a given land class the model should help determine the amount and quality of recreational experiences gained or lost in exchange for gains or losses in non-recreational or competing recreational uses.

Presumably, changes, through use, in ecological, social, or managerial components of settings that would alter the ROS class delineation could be identified and stopped if deemed necessary. Clark and Stankey (1979), however, point out the potential for "inadvertent inconsistencies" to develop in ROS classes as a result of subtle, incremental, and cumulative changes in setting components. A simple example might be an improvement in access to an area that is consistent with the ecological component of a setting, but that encourages greater recreation use resulting in an inconsistent social component for the setting.

Stankey and others (1985) have proposed a refinement to the ROS model known as the Limits of Acceptable Change (LAC). They propose a nine step process for implementing the ROS in wilderness areas in which specific resource and social conditions that are desirable, achievable, and measurable are defined. The process includes steps to specify indicators of resource and social conditions, standards for resource and social indicators, and to monitor the indicators and conditions for change. Managerial actions can be designed to halt or promote change according to management goals.

The steps permit the identification of critical biophysical indicators of potential change in ROS class delineations. It would be a useful addition to the ROS model to adapt several of the LAC steps to the ROS analysis of all forestland areas (not just wilderness areas). In particular, LAC adds a dynamic, temporal feature to the ROS model. The monitoring step is tied directly to specified indicators and standards of change. However, the explicit linkages between various biophysical and social conditions and the kind and quality of different recreational experiences remains judgemental. Until the linkages are known with greater certainty and consistency, expert opinion can be used to approximate the exact relationships.

Rauscher (1987) provides some definitions of an "expert system." To paraphrase, expert systems are a subfield of artificial intelligence. They employ knowledge and inference procedures to solve problems. They are designed to mimic human reasoning processes that depend upon a knowledge base provided by human experts. Application of the ROS to ponderosa pine forests by "expert" foresters, recreation specialists, and landscape architects can provide a useable knowledge base. Fairweather (1987) generally describes an expert system computer shell called RuleMaster. This system is rule-based. That is, it employs a procedural decision process analogous to a decision tree. The procedure is based on rules, or declarative knowledge, supplied by experts. Given a set of related, declarative facts (stimulus), conditional "if, then" arguments are formed, proceeding stepwise toward a solution (response).

Following a suggestion by Jubenville and others (1986), a simulation model framework can be conceived that simulates biophysical responses to management actions. These authors describe a framework designed to assess wildlife habitat impacts resulting from economic development. They note, also, that a parallel application could be made for the ROS.

Using the six opportunity classes defined by the Forest Service, an Opportunity Class Index (OCI) can be formed. The OCI could range from one to six, an arbitrary scale representation of the ROS. That is, an OCI of one would represent a primitive ROS opportunity class and an OCI of six an urban class. When multiplied by a geographic measure, such as acres, a "quantitative" measure of recreation potential for a forestland area results. Subjectively determined gradations between one and six would represent the spectrum of opportunities, by geographic sub-area, for a forest area at a point in time. This output could be measured as Experience Opportunity Units (EOU's) by ROS class. EOU's in a given class would be weighted by the inverse of the OCI for that class to make EOU's across classes equivalent. Changes in EOU's over time would reflect the variable responses to management stimuli.

The relationship between recreation opportunity classes and the ecological, social, and managerial components must be expanded to allow for the subjective determination of the OCI. Six mutually exclusive environmental conditions are postulated for the model that result from specific combinations of biophysical (ecological), social and managerial components. Each component can take on a value of 0 or 1. The values of components for an environmental condition are multiplied and then weighted, progressively by thirds, from 0.333 for Environmental Condition I to 2.000 for Environmental Condition VI.

LAC-type indicators, as defined by standards, are used to make a qualitative suitability assessment of each component for an Environmental Condition on a scale of 0 or 1. Implied in the relationship between indicators and the assessed value of the components are linear, or non-linear mathematical relationships. However, the complexity of these relationships presents a formidable task for modeling them with explicit mathematical functions. An initial approximation can be derived by developing a system of relationships based on expert judgments.

RuleMaster is one example of a system shell that might be employed to provide EOU's. The shell could be coupled with forest simulation models for overstory or other biophysical, social, or managerial indicators of change. As indicators change under various simulated conditions, EOU's by ROS class can be determined.

Scenic Beauty Models

A number of different approaches have been developed for assessing the scenic beauty or scenic quality of landscapes. Each approach adopts or implies a somewhat different concept or definition, but each may be traced to the concerns expressed in environmental protection legislation of the 60's and 70's for "natural scenic beauty." Daniel and Vining (1983) and Zube and others (1982) present reviews of methods and conceptual bases for the major approaches, along with discussions of the advantages and disadvantages of each. This section will focus on what both reviews identified as the "psychophysical approach" as exemplified by the Scenic Beauty Estimation or SBE method introduced by Daniel and Boster (1976).

The SBE method is a system for measuring and modeling landscape esthetics, based on the perceptual judgements of human observers. Observer panels, usually of 30 or more people, are typically sampled from the general public or from some other population of interest. The SBE method is an adaptation of classical psychological methods developed by psychophysicists around the turn of the century. It relies on concepts and procedures developed by Thurstone (1927), and described in detail by Torgerson (1958) with some extensions developed by signal detection theorists such as Green and Swetts (1966).

Most of the research in landscape assessment has relied on photographic representations of the assessed landscapes. The remoteness of many of the areas for which assessments have been required, such as forests, wilderness areas and other wildlands, has made

the costs of having adequate numbers of observers sampled from the public directly view these areas prohibitive. A further inducement for the use of photographic representations is the difficulty of achieving adequate experimental control in actual field settings (as in the order of presentation and the observation/judgement context). The use of photographs as surrogates for actual landscape/environments raises several issues having to do with the validity of such representations. One concern, for example, is with determining which of the very large number of potential scenes available in a forest area should be selected to represent that area. Another concern is that pictures may not convey all that is potentially important to human aesthetic response to landscapes.

A number of studies have systematically addressed the issues that arise in using photographic surrogates in landscape assessment. View sampling procedures, photographic quality requirements, and viewing context have all been studied. The results from a large number of studies (Daniel and Boster 1976; Kellomaki and Savolainen 1984; Shafer and Richards 1974; Stewart and others 1984) have agreed that scenic beauty assessments based on appropriately sampled and presented color photographs (typically projected color slides) are consistently very closely correlated with assessments of the same areas when viewed and judged directly on site.

As with all psychophysical procedures, some overt indicator response must be selected; i.e., the observer must overtly indicate which landscape is preferred, or judged to be of higher scenic beauty. For landscape assessment applications, indicator responses have ranged from rather simple paired-comparisons to more complex magnitude estimation procedures.

The SBE method has typically employed a categorical rating scale procedure coupled with transformations consistent with Thurstone's (1927, 1959) "Law of Categorical Judgement." Observers are required to independently rate the scenic beauty represented by each of a number of landscape scenes using a 10-point scale, where a 1 on the scale indicates very low scenic beauty and a 10 very high scenic beauty. The rating procedure was found in studies by Daniel and Boster (1976) and by Buhyoff and others (1982) to yield perceived scenic beauty scales (after appropriate transformations) that were empirically very similar to those produced by paired-comparison procedures.

At the current time, the psychophysical approach to scenic beauty assessment has essentially converged on the use of systematically sampled photographic representations of the assessed landscapes and categorical rating scales for the response indicator.

The scenic beauty assessment procedures described above represent only the first component of the psychophysical approach. The second component is the specification of the relationship between the scenic assessments and the physical features of the assessed landscapes. Early efforts in this regard relied on relatively simple correlation methods (Daniel and Boster 1976). More recently, multi-variate statistical techniques, in particular multiple regression analysis, have been employed (Arthur 1977; Buhyoff and others 1982; Brown and Daniel 1984; Schroeder and Daniel 1981; Schroeder and Brown 1983).

Scenic beauty models developed within the SBE approach have generally been based on directly measured "manageable features" of the landscape. That is, the perceived scenic beauty indices, SBEs, for a set of landscapes are related to objectively measured features of those landscapes, such as the number and size of trees, the amount of grasses and other vegetative ground cover and the volumes of down wood on the forest floor.

The particular physical characteristics selected as independent variables for the SBE models were chosen because they are the variables that are typically measured (inventoried) and manipulated in the context of forest management; a major goal of the SBE method was to be able to inform forest managers of the scenic implications of various management actions. Also, it has become increasingly common practice in forest planning to make management decisions based on explicit quantitative predictions of expected changes in forest characteristics. Predictions are generally made by a set of computer implemented environmental simulation models that project changes in the biological components of the forest based on modeled management actions and/or natural events such as insect infestations, drought, fire or ecological succession. Thus, the ability to link projected changes in the biological features of the forest landscape to changes in perceived scenic beauty is essential if "natural scenic beauty" is to play an appropriate, congressionally mandated role in the management of the nation's forests.

Daniel and associates (Arthur 1977; Brown and Daniel 1986; Schroeder and Daniel 1981; Schroeder and Brown 1983) have developed a number of models that are applicable to southwestern ponderosa pine forests. While a number of assessment studies have been done, there are not yet any SBE models available for mixed conifer, spruce fir or other important forest types.

All of the above models have been developed for predicting scenic beauty in the context of the "near view" perspective, i.e., for viewing

situations in which the viewer is within the forest canopy and where views are generally restricted to a few hundred feet. Further, most of the forest areas modeled in this way have been either essentially natural, undisturbed areas or areas where human disturbance (e.g., timber harvest) was sufficiently in the past that the area had recovered to a relatively stable state and appeared undisturbed. Brown and Daniel (1984) investigated recently harvested ponderosa pine stands and found that "pre-harvest" models were not good predictors of immediate post-harvest forest stands. They were not, however, able to develop adequate post-harvest models with the limited data set that was available for their study. Given the goal of being able to project the scenic consequences of various forest management alternatives, there is clearly a need for the development of post-disturbance (especially timber harvesting) scenic beauty models.

Near view perspectives are important in many forest areas, representing views frequently experienced by hikers, campers, picnickers and those driving along forest roads. However, more expansive views of the forest landscape, as from overlooks that provide views over large areas of forest, are often much more important. Indeed, these "vistas" are probably what most often comes to the mind of the public when reference is made to "forest scenic beauty," and has been the primary concern of the forest landscape architects' expert assessment systems. Efforts to quantitatively model vista scenic beauty have been somewhat more restricted, and substantially less successful, than the near-view models. Perhaps the earliest efforts were those of Shafer and his associates (Shafer and Meitz 1970; Shafer and Richards 1974). In these studies scenic beauty rankings were related to measures of features of photographs of landscape scenes such as the perimeter of various vegetation types in different locations on the photograph.

Both the early Shafer studies and the later efforts by Buhyoff found that variations in vista scenic beauty judgments could successfully be accountd for by measures of the composition of the landscape scene taken from photographs. A serious limitation of these models, however, is that the independent variables are based on picture-plane measurements made from photographs (e.g. "perimeter squared" of foreground vegetation). While it has been shown that these measures are related to perceived scenic beauty indices based on observers reactions to the pictures, it is unclear how these picture variables are related to the bio-physical characteristics of the landscapes represented in the pictures. This is an essential relationship if these vista models are to help project the scenic consequences of forest management actions that are to be implemented on the ground. There is, then a clear need for further development of vista scenic beauty models that can be more directly related to, or based on, bio-physical features of the forest landscape.

THE RELATIONSHIP OF SCENIC BEAUTY TO RECREATION MODELING

Conceptually, forest scenic beauty is a component of a total recreation experience. The visual quality of a recreation environment is important, among several reasons, because people simply enjoy the natural beauty of forest scenes, and because the appearance of a recreation environment provides an indication of congruity with desired experiences. In other words, for forestland recreation the appearance of a place determines, in part, its suitability for certain activities or experiences. Visual quality is, however, only a part of the experience, and, presumably, varies with different activities and experiences. For example, activities involving tests of skill, such as fly-fishing or white water kayaking may be less dependent on the attractiveness of the surrounding scenery than more contemplative experiences such as picnicking or hiking.

Recent studies directed at assessing the relationship between forest scenic beauty and the quality of recreation experiences suggest that the scenic beauty of the surrounding forest is an important contributor to the value of the experience, as measured in economic terms. However, the value of recreation experiences, even in specific settings, is apparently affected by more than the biophysical elements; facilities and social conditions affect experience values as well (Brown and others 1988, Daniel and others 1989).

In any case, although forest scenic quality is relatively important to the recreation experience it is but one of a host of contributing factors. Models of scenic beauty, therefore, would logically be subroutines to a more general recreation experience model. The forest scenic beauty models developed for near view quality estimation (SBE) are explicitly related to biophysical factors of the forest environment.

Forest scenic beauty models, then, are potentially useful mechanisms for delineating ROS classes in terms of the appearance of the biophysical component of each class. It is not clear, however, at this time, how scenic beauty based models might vary with different experiences or activities. It is reasonable to assume, at least, that the same biophysical factors that contribute to scenic beauty would be indicators of change in the LAC process of monitoring ROS class integrity.

Another way to conceive of a modeling relationship between scenic beauty models and general forest recreation models is with a parallel configuration. Scenic beauty models could be incorporated into simulation routines, and used to generate simultaneous output with an ROS based model, also driven by the same simulation routine. ROS classes would be delineated by area over time along with an assessment of scenic beauty for the same areas.

SUMMARY OF RESEARCH FINDINGS AND FUTURE NEEDS

The literature on recreation and esthetics research, as discussed throughout this paper, shows that the findings are generally tentative, and in some cases inconclusive. This is attributable to the relative recency of a formal and systematic investigation of relationships between natural resource based causal factors and desired wildland recreational outcomes or situations. The findings, nonetheless, are impressive. The ROS concept is a major simplification, but apparently useful model, of a very complex sociopsychological relationship to the natural environment. Still, explicit response functions, with known variables and parameters, remain to be fully expressed and verified.

The simulation model framework for recreation presented in this paper provides a non-specific expression of relationships among stimulus and response variables in the production of recreation experiences. As an initial approximation to specific relationships the judgement of experts is proposed to express the functional parameters of the expected relationships. The variables critical to the relationships have been hypothesized in research activities, but not definitively estimated.

Near view scenic beauty models are more clearly defined in terms of critical variables and parameters. The relationship between measurable biophysical forest characteristics and the perceived scenic quality of forest conditions has been statistically defined. The addition of a temporal component to near view scenic models is still needed, but the causal factors affecting changes in scenic beauty over time should be among the critical biophysical factors already determined for these models. The extensive research accomplishments reviewed in the section on scenic beauty modeling reveal well developed models for the near view. Far view scenic models need to be further developed and refined. In this case, however, the important causal factors remain to be clearly specified.

The recreation and esthetic research accomplished to date clearly suggests the general natural or biophysical characteristics that must guide future research into the biophysical component of recreation settings. Forest overstory vegetation condition, including density of tree stocking, crown closure, species composition, and age classes is an important aspect of the biophysical component of a forest recreation setting. In turn, overstory condition affects understory vegetation. Scenic beauty models, at least, reveal that understory vegetation has a significant positive influence on forest scenic quality. Riparian conditions, especially with lakes or streams, enhance most recreation settings. Major geologic features also are believed to contribute to recreation experiences.

Much less is known about particular aspects of the social and the managerial components of recreation settings. Research is needed on the desired sociability levels for specific recreation activities. Similarly, the appropriate levels and types of regimentation for different recreation activities or experiences need to be determined.

Near view forest scenic beauty models can be improved by the specification of variables that reflect changes in scenic quality following major alterations in biophysical conditions of settings. Post-timber harvest or post-fire conditions are common in forest settings. It would be useful to determine measurable vegetative conditions that mitigate detrimental effects to scenic quality due to major changes in biophysical conditions. Also, methods to evaluate such changes on the perceived scenic value of far view, or vista, scenes need to be developed. Far view scenes, by their nature, are much more complex, containing many more factors, beyond commonly measured forest elements, than near view scenes. This makes them less tractable for modeling the significant management stimulus variables that contribute to the quality of the scene. In many cases, the significant factors affecting the quality of far view scenes such as weather effects or mountainous terrain, are beyond human control. In southwestern ponderosa pine forests, however, where terrain is generally flat, far view scenes are less complex and often relatively unimportant. It would be useful to know how important far view scenes are in the management of ponderosa pine forests.

Another emerging technology that promises to be very useful in the assessment and modeling of forest scenic beauty, especially for vista landscapes, is based on digital image processing and "paint program" technology that has recently become available and easier to use on micro-computer systems. The basic approach here is to photograph and digitize individual forest scenes, and then to use image processing software to modify features of the scene. Once the image is digitized, special image processing, paint and cut-and-paste routines can be used to manipulate

the image. For example, selected trees in a forest scene can be changed in color (to simulate defoliation or other damage), removed altogether, or replaced by other trees "cut" from other parts of the scene or from another digitized scene (Orland, In press).

A key advantage of digital image processing procedures is that very realistic representations are achieved; the resolution and color quality of the manipulated images are comparable to that of standard color television. Most importantly, however, the digital image processing technology offers a means to experimentally manipulate specific features of a landscape scene while other features are held constant. The realism and flexible feature manipulation capabilities of digital image landscape simulations make this approach most suitable for investigations of public landscape perceptions. The digital image approach offers a very powerful new means for testing and extending scenic beauty models in both near-view and vista contexts. This new technology will undoubtedly play an increasingly important role in future scenic beauty assessment and modeling research.

Initially, a research effort focussed on the validity and reliability of the expert opinions employed in the proposed ROS-based, expert judgement system model should be undertaken. Using the experience setting descriptions developed by the Forest Service, expert opinions would be used to develop decision criteria for the model. Application of the model (simulation) could be undertaken on several geographic locations to test the sensitivity of the procedure and the validity of the judgements. Reliability of the model, as measured by its utility in numerous diverse geographic locations within the southwestern ponderosa pine type could also be determined. Refinement of the model in this manner will lead to more complex research needs for the specification of precise relationships between recreation setting components and experiences.

Eventually, specific indicators of biophysical, social, and managerial conditions must be ascertained, along with standards by which changes in conditions can be measured. For example, to what degree is human influence on the biophysical component of a recreation setting evident to most recreators? Can vegetative succession following human intrusion into natural environments obscure the efforts sufficiently to provide primitive recreational experiences? What level of human intrusion would provide a roaded natural setting for recreation?

Similar questions can be posed for the social and managerial components of recreation settings. The objective of the research endeavor in each case should be to identify measurable indicators that serve to define a recreation experience class. Those indicators critical to the class definition could then be selected. For example, important biophysical indicators for the semi-primitive, motorized experience class might be tree spacing, essentially undisturbed understory vegetation, and non-maintained roadways. Corresponding social and managerial indicators could be contact with a maximum of three other parties per day, and no regulatory signs, respectively. Such measurable indicators permit standards to be specified by which changes in condition can be assessed. Continued research into social carrying capacity and the psychological satisfaction derived from different settings is necessary.

Research into the relationship between forest scenic beauty models and ROS based models would logically follow from the research efforts described above. How important is scenic quality to different recreation experience classes? Does the assessment of scenic beauty of a forest setting help to define that setting's experience class? More exactly, are the critical biophysical indicators for scenic beauty models the same as those that help define a recreation experience setting?

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Uncertainty and Risk in Forest Management[1]

Aregai Tecle, Lucien Duckstein, W. Wallace Covington, and D. Brent Wood[2]

Abstract.--A framework is developed for risk and uncertainty analysis in forest management. The elements of this analysis are driven by five main issues, the first of which is forest regeneration. The first framework element is the set of hazards such as fuel and weather conditions that create a fire hazard; the second element is the set of hazardous events triggered by some random element, such as a forest fire ignited by lightning. The third element is the set of actions or decisions, and thefourth one consists of criterion functions, such as loss of wildlife habitat as a result of fire. A probabilistic model which is applicable to any risky situation is developed, in which the uncertain parameter is taken as a function of the hazard descriptors.

INTRODUCTION

The purpose of this paper is to provide a framework for risk analysis in forest management. This framework is analytical and includes uncertainties due to, for example, weather and climatic forecasting. The methodology is illustrated by means of an analysis of forest fires, as well as other hazardous events, and is developed for application to decision support systems such as the Terrestrial Ecosystem Analysis and Modeling System (TEAMS) of Covington and others (1988) which has been used for both educational and forest management purposes (Wood and others 1989).

Risk analysis is a procedure of determining the probability of occurrence of a particular undesirable state of nature. The occurrence of a particular event may be uncertain if we do not have any knowledge about its probability occurrence. A complete risk analysis under uncertainty may be performed according to the following steps (Duckstein and others 1989):

1. Identification of the hazard, H, for example, large quantities of fuel coupled with hot, dry weather and electric storms (lightning).

2. Estimation of the probability, $P(H|\theta)$, of the hazard, H, where θ is a parameter vector depending on the hazard triggering factors such as lightning or throwing a burning match stick or a burning cigarette butte in a forest environment.

3. Definition of the hazardous event, x, and estimation of the conditional probability, $P(x|H, \theta)$, of the occurrence of the event.

4. Determination of the consequences, L, of the hazardous event, for example a loss of habitat of a given wildlife species, siltation of downstream reservoir.

5. Evaluation of the effects of remedial, control or management activities Aj on the consequences (L), such as the effect of timber harvesting on wildlife losses, or the effect of forest tree regeneration on sediment loss. The function L may be single dimensional (e.g., economic), or

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multi-dimensional in nature. This step thus involves two tasks:

5a. definition of the set of available actions or decisions $\{A\} = \{A_1, \ldots, A_J\}$.
5b. definitions of a set of objective, criterion or loss functions $L(x,A)$.

6. The output of such a risk analysis is a set of probability distributions and criterion values including risks.

7. The output may be presented in a decision support system, which includes two or three-dimensional maps of the area under consideration.

These seven analysis steps are related as sketched in Figure 1. In the next section, the issues pertaining to the consequences of hazardous events on forest management are first listed (Step 4 above and in Fig. 1), to focus the paper on relevant elements.

ISSUES

By issues we mean the physical consequences of hazardous events such as fires, floods, or droughts on the forest system. Five issues are considered in this paper.

I1. Forest regeneration after a destructive event, such as clear cut harvest, or fire, measured as the number of saplings per unit area per time period (in years) after the event.

I2. Threat to an endangered species measured as a decrease in the population of a particular species that serves as an index of habitat capability.

I3. Deterioration of wildlife habitat measured as percent destruction of the habitat.

I4. Aesthetics degradation measured as change in scenic beauty estimator.

I5. Water yield measured both in volumetric and economic units, and water quality, measured by indices of concentration of pollutants.

These five issues are related both physically and statistically. In particular, the first one, (I1) forest regeneration, is strongly related to the four other issues. Next, a set of hazardous events, corresponding to Step 3 in figure 1, is described.

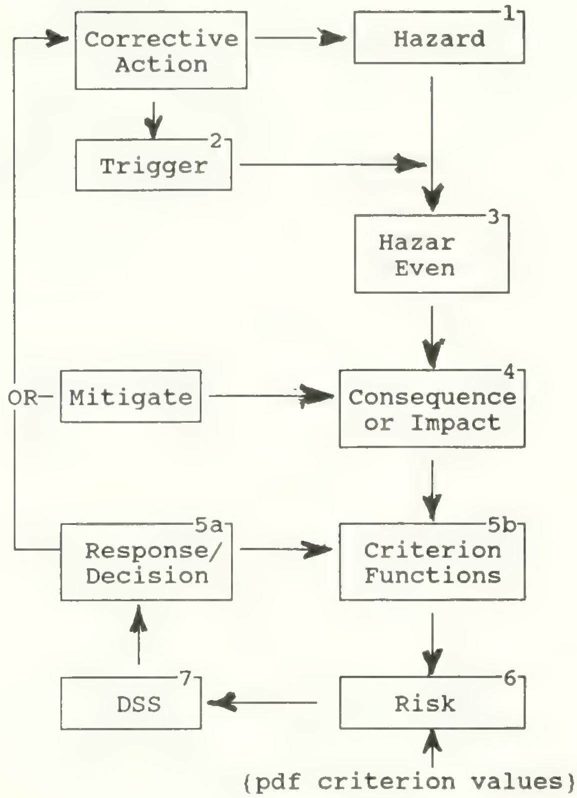

Figure 1. Diagrammatic Representation of Risk Analysis Procedure

HAZARDOUS EVENTS

Here, five broad categories of hazardous events are listed. Again, there may be physical and statistical dependence among several of these events.

E1. Fires, either wildfire or controlled burning, are influenced by unexpected disturbances. These disturbances may be due to natural processes such as volcanic eruption, and lightning, or anthropogenic in origin such as camping and other recreational use.

E2. Extreme weather or climatological phenomena, such as intense precipitation or prolonged droughts.

E3. Erosion which may be caused by either natural or man-made hazards.

E4. Atmospheric pollution, such as sulfur from smelters or power plants, and acid rain.

E5. Human caused stress stemming, for example, from grazing, harvesting activities, pollution loading, or exceeding the capacity of a recreational area.

Two conditions are necessary for a hazardous event to occur:

(a) A hazard must be present (e.g. fuel)
(b) A triggering mechanism must be activated (e.g. ignition of fuel through lightning).

These two conditions, corresponding to steps 1 and 2, respectively, in figure 1, are described in the following sections.

HAZARDS

A hazard is a situation which may lead to or cause an unfavorable events to occur. For example, a loaded gun pointed at a person is a hazard. And if the trigger is pulled, the hazard results in injury or death, which a hazardous event. The event is determined by the presence of both the hazard and the trigger. This implies that the presence of a hazardous environment does not necessarily entail a hazardous event. The occurrence of the latter can be prevented either by correcting the hazard, or by avoiding any mechanisms that may trigger the occurrence of a hazardous event.

Hazards, **H**, in forest management which relate to the issues described in above include the following:

H1. Fire hazard which increases amount and areal distribution of fuel accumulation, dry and hot weather conditions, combined with a high probability of occurrence of an ignition triggering mechanism such as lightning or human-induced fires.

H2. Timber harvesting combined with steep slope conditions and easily erodible soil characteristics is a hazard which may enhance soil erosion, flooding, loss of wildlife habitat, etc.

H3. Extreme rainfall or drought conditions may have devastating effects on the fauna and flora in a forest system. Both extreme rainfall and drought conditions are considered to be hazards because each has the capacity to cause unfavorable events. Extreme rainfall, for example, may cause flooding, loss of crops, or young trees. Likewise, drought may cause loss of wildlife, or stunt or destroy the healthy growth of forest trees.

H4. Grazing activities which cause overgrazing and soil detachment through tramping the ground by livestock may in turn make the ground amenable to erosion, and decrease the amount of the rainfall that can infiltrate into the soil.

H5. Pollution hazard caused by an existence of emission source combined with necessary wind conditions; the triggering mechanism is the operation of the emission source and the event is the resulting level of air pollution.

H6. Transportation policy - building of roads, allowing access to off-road vehicles, and frequency of vehicular use.

As previously pointed out, each of these hazards may cause a hazardous event, but not necessarily so. For example, grazing combined with intense precipitation may or may not cause erosion; also, a thunderstorm over forest fuel does not always result in a fire.

Actions that may be taken to prevent or mitigate the effects of hazardous events (Step 5a in Figure 1) as well as some possible criterion functions (Step 5B) are listed in the next section.

ACTIONS AND CRITERION FUNCTIONS

Actions include, but are not limited to the following alternatives:

A1. Harvesting, including transportation of products.
A2. Selective cutting and prescribed burning.
A3. Artificial regeneration.
A4. Grazing policy.
A5. Recreation capacity setting policy.
A6. Transportation policy.
A7. Information dissemination.

Criterion functions include, as mentioned earlier, the following items:

C1. Forest regeneration scale.
C2. Habitat (area type and quality, alos food and shelter) of endangered species.

C3. Wildlife conditions (number, diversity and health condition).
C4. Aesthetic scale.
C5. Water quantity, value of water for various water supply uses (hydrologic) and water quality indices.

STOCHASTIC METHODOLOGY

Consider only fire hazard H1. The first phase of the study is to determine the probability of the hazardous event. The probability of a hazardous fire event is sought directly, as

$$P(X=x|\theta(H)) \qquad (1)$$

where $\theta(H)$ is the parameter of the probability density function (pdf) of x. Assume, for example, that the probability of fire at a given site follows a Bernoulli or point binomial pdf with mean θ. This relationship is represented by:

$$F_x(x|\theta)) = x^\theta(1-x)^\theta, \qquad (2)$$

where x=0,1 and $\theta\epsilon[0,1]$

In this analysis, θ itself is a random variable, with a probability density function (pdf) $g(\theta)$ to be determined by combining various sources of information. Thus, a linear regression of θ in the elements of hazard (H) may be performed. For instance, let fire hazard (H) be a function of fuel (B), dryness (D), temperature (T), wind speed and direction (W), number of lightning strikes (N), then a regression equation expressing the relationships between these elements can be constructed in the following form:

$$\theta = a_1+a_2B+a_3D+a_4T+a_5W+a_6N+\epsilon \qquad (3)$$

Remember that θ is the <u>mean</u> probability of fire occurrence if the conditions described by the values of the independent variables are present. The <u>actual</u> occurrence is represented by a non-controllable random variable x which can take on values of either 0 (no fire) or 1 (fire).

If equation (3) is used, then θ has the pdf of ϵ, which is taken as a normal distribution, $N(0,\sigma,\epsilon)$ with a mean of 0 and standard deviation σ. This pdf should be truncated since θ is an element ranging in value between 0 and 1, $(\theta.\epsilon.[0,1])$. Other sources of information can be combined with the model in equation (3) in particular:

- regional information stemming from the same type of forest at different sites
- model based information (simulation)
- subjective information assessed from experts
- observation data

Bayes Theorem is used to pool all sources of information together. For example, a subjective pdf $g(\theta)$ is combined with the information $N(\theta|REG)$ given by the regression by applying Bayes Theorem to obtain a so-called posterior pdf of θ.

$$g(\theta|REG) = Kg(\theta)N(\theta|REG) \qquad (4)$$

where K is a normalizing constant.

Once a model such as the one in Equations 3 and 4 has been calibrated, a forecasting of the weather related variables D,T,W, and N, together with an estimation of fuel amount B, yields an estimate of fire hazard (θ) encoded as the mean of pdf in Equation (2). The probability of fire event can then be estimated from Equation (1).

MULTICRITERION ANALYSIS

Next, every criterion function Ci, i=1,...I, here I=5, can be expressed as a function of action Aj, j=1, ...,J, here J=5 and hazardous event x (Tecle et al. 1988) as follows:

$$Ci = Ci(Aj,X) \qquad (5)$$

The expectation of C_i over X yields a function of θ, whose expectation must again be taken, thus

$$E^\theta E^x(Ci(Aj,X)) = E^\theta(Ci(Aj,\theta)) = Ri(Aj) \qquad (6)$$

which is a so-called "risk cost."

The action or decision is sought, which minimizes Ri(Aj). This formulation makes it possible to calculate the worth of perfect and of sample information (Davis and others 1972; Ang and Tang 1984).

SUMMARY AND CONCLUSIONS

A framework has been developed to study uncertainty and risk in forest management. In the example presented herein, the framework is driven by five issues, and includes six hazards, five hazardous events, five criterion functions, and seven possible actions. Only the uncertainty in the weather

variables has been considered; it is encoded for example as the random mean of the pdf of hazardous event occurrence X, which, here, has been taken as a Bernoulli variable for the sake of simplicity.

The framework which makes it possible to combine multiple sources of information leads to the use of multiple criteria (Tecle and others 1988) to evaluate the consequences of a hazardous event and determine the appropriate action for mitigating or controlling the effects of such an event.

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Trends in Residential Development and Water Usage Below the Mongollon Rim of Central Arizona[1]

Alvin L. Medina[2]

Abstract.--Trends in home development within the ponderosa pine type were examined for the region of central Arizona. Home development rates spiralled since the mid-1950's, with about 92% of all homes constructed since 1955. The potential for additional development in the region is greater than 2-fold, since about 47% of private lands remain unsubdivided and about 50% of subdivided lots remain undeveloped. Increased demand for domestic water has paralleled home development to the extent that development has declined due to the lack of water. In the community of Pine, for example, consumption rates exceed the amount provided by stream base flows.

INTRODUCTION

Second-home development in rural areas of the Southwest has increased greatly in recent years. In Arizona, several economic and social factors, including rapid population growth, prosperity, and increased land value, have influenced second-home development in the Mogollon Rim region (Bond and Dunikoski 1977, Lindquest 1972). Homes and land subdivisions along riparian zones and in high-elevation ponderosa pine forests are in greatest demand because the stream and forested environments are esthetically pleasing and water is available. As a result, water consumption by home subdivisions has increased proportionately with development, resulting in limited water supply for some communities and changes in perennial streams. These changes in streamflow potentially threaten riparian vegetation and fishery resources, although these threats are difficult to assess directly or indirectly (Bormann et al. 1970).

Various researchers have examined water related problems (i.e., quality, socioeconomic) associated with second-home development (Brickler and Utter 1975, Lewis 1980, Morgan 1978, Ponce and Dederick 1979, Segall 1975). However, most studies were primarily concerned with assessing the impacts on water quality. Still other studies (Johnson and Carothers 1982) have focused on recreational problems affecting riparian habitats. Information on the trends in home development and water consumption for forested areas in the Southwest is scant, and limited mainly to unpublished reports (Bond and Dunikoski 1977). Therefore, this study specifically (1) examined the trends in regional residential development within the ponderosa pine type of central Arizona, and (2) relates water usage by a typical community of Pine, Arizona to potential regional development.

STUDY AREA

The study area is near the geographic center of Arizona in northern Gila County, immediately below the Mogollon Rim escarpment and on the Payson Ranger District, Tonto National Forest (Fig. 1). Steep, mountainous canyons emanating from the escarpment dissect the landscape from east to west. Vegetation consists of Petran Montane Conifer Forest (Brown and Lowe 1980). The ponderosa pine type is interspersed with the Great Basin Conifer Woodland type.

Nearly 65% of total precipitation occurs in winter, primarily as snow. Summer precipitation is by localized monsoon showers. Mean annual precipitation is 635 mm and ranges from 550 to 760. Mean annual temperature is 14°C and ranges from -10°C to 32°C. Base flows of 42.5 l/sec are common in most creeks, with peak flows greater than 170 m^3/s (USDA Forest Service 1966). The origin of most streams is groundwater flow, which emanates from the Coconino sandstone-shale contacts found on the south face of the Mogollon Rim escarpment at elevations of about 2180 m.

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[1]Paper presented at the symposium on multiresource management of ponderosa pine forests [Flagstaff, Ariz., November 14-16, 1989].
[2]Research Range Scientist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Arizona State University Campus, Tempe, Ariz. 85287-1304 (U.S.A.).
[3]Peterson, Mike. 1989. Personal communication. Gila Co. Dev. Div., Globe, Arizona.

Figure 1.--Location of study area below the Mogollon Rim on the Payson Ranger District, Tonto National Forest.

The region is a popular vacation, retirement, and recreation center. Summer residents exceed permanent residents 2- to 3-fold. Commercial sectors are heavily dependent on tourism, summer residents, and recreationists (Arizona Department of Commerce 1986). Settlement of the area, which started near 1890, consisted mainly of cattle ranchers until recently.

Residents of Pine, Arizona use stream water from Pine Creek for irrigation and domestic purposes. A detention dam constructed in 1965 in Pine Creek above the community diverts upstream water, which is piped to the residential area below. Between May and October, most of the piped flow is used for irrigation by residents having water rights. This diversion causes ephemeral flow in the stream reaches below the detention dam during the summer. In contrast, base flow above the diversion during the summer is maintained at approximately 45 l/s (USDA Forest Service 1966).

METHODS

Trends in home development since 1885 for the region were determined by examining Gila County plat records (Redi-Data 1987) and recording the number of homes constructed. Records were examined for areas only within the ponderosa pine type indicated on figure 1, all of which are within the Payson RD. Only private homes were used for this analysis. Construction trends were graphed to show differences among years. Residence was determined from local addresses listed in the county records. Numbers of vacant lots available for development were also noted. Of the roughly 4,000 ha of private land within the study area, about half are subdivided for home development. Records from the local water company (E & R Water Company, Inc., Mesa, Arizona) were used to estimate water consumption for the community of Pine.

RESULTS

Regional housing development trends are shown in figure 2. Only about 8.1% (362 homes) of all homes built by the end of 1987 were constructed prior to 1956. The percentage of the total doubled (17.8%) between 1956 and 1960 and nearly doubled (33.4%) again between 1961 and 1970. The largest percent increase in housing development occurred from 1971 through 1985, with a 16.2% increase between 1966-1970 and 1971-1975, 24.7% increase between 1971-1975 and 1976-1980, and 23.6% increase from 1976-1980 to 1981-1985. Approximately 92% of all homes were constructed since 1955. Although 4,454 number of homes were built between 1885 and the end of 1987 within the ponderosa pine type, about 47% of private parcels still remained undivided. Thus, the potential for additional home development in the region is greater than 2-fold.

Nearly 62% of the residences were owned by nonresidents, i.e., people outside the local mailing area, with most being from the Phoenix or Tucson metro areas (fig. 3). Nonresidents make general use of their temporary residences primarily during the summer months (May through August) and weekends. Most homes are constructed in streamside environments (fig. 4) and on adjacent slopes and ridges.

Average monthly water consumption rates per household in the community of Pine were roughly 10,730 liters for the period 1975-1985, based on an average of 1,602 households. Winter and summer consumption rates were about 8,500 liters and 12,950 liters, respectively. The largest use (mean=45.1%) occurred during the summer from June through August (fig. 5), which coincides with the period of low flow in Pine Creek and the influx of summer residents.

DISCUSSION

Home development in the region increased dramatically after World War II. One plausible explanation for this rapid growth may have been increased affluency of nonresident owners from the metro areas of Phoenix and Tucson, who own nearly three-fourths of the residences. Reasons for owning a residence in the forested environment are probably a desire to escape from the valley heat during the summer and weekends and recreate in the general area, investment in real estate, and preretirement plans. Records show most lots could be purchased for about $4,000 to $6,000 in the 1950's (Redi-Data 1987). Current prices for similar lots range from $25,000 to $30,000, and up to $60,000 for improved lots. Figure 3 indicates a general increase in home ownership by residents, who are likely retirees. The sharp decline in construction after 1985 was probably due to a variety of reasons, including adoption of more stringent building codes by Gila County, reduced federal income tax opportunities for second homes, and a building moratorium imposed in the Pine community because of water shortages.

The growth rate observed during the last 15 years, especially along streamside environments, undoubtedly increased the demand for water from streams that are only capable of supplying a limited amount of water. Early accounts of water usage for the area report an ample supply of "good" water from creeks, springs, and streams during early 1900's, but by 1930 drilled wells were needed to supplement surface waters (Northern Gila County Historical Society 1984). Bond and Dunikoski (1977) also reported considerable variation in average water usage patterns throughout the region. They estimated an average annual use of 74,409 l/household and a summer usage rate of 11,570 l/household/month for a residential area in Pine. This estimate is lower than the 12,950 l/household/summer-month reported here.

Using the reported average number of 1,602 households and a summer use rate of 12,950 l/household/month for the Pine area, water usage is about 20.7 x 10^6 l/summer-month or roughly 20,746 m^3. The flow of 135 l/s from the detention dam provides about 5,832 m^3, or about one-fourth, of the estimated summer demand. The deficit is made up from ground-water wells. These calculations show the community may be using more water than base flows in the stream provided during the summer months. During the summer of 1989, the water shortage became severe enough that domestic water was trucked in to the community. In addition, about 45% of all home tracts sold remain vacant, hence the potential demand for domestic water could double or reach about 41,500 m^3. Additional water is also needed by commercial enterprises, fire suppression and other unspecified uses.

There are other potentially negative impacts that could be associated with residential development in forested environments. Some of these include a general loss of habitat for wildlife as a result of site development, roads, and increased human disturbance. In some cases,

TREND IN RESIDENTIAL DEVELOPMENT

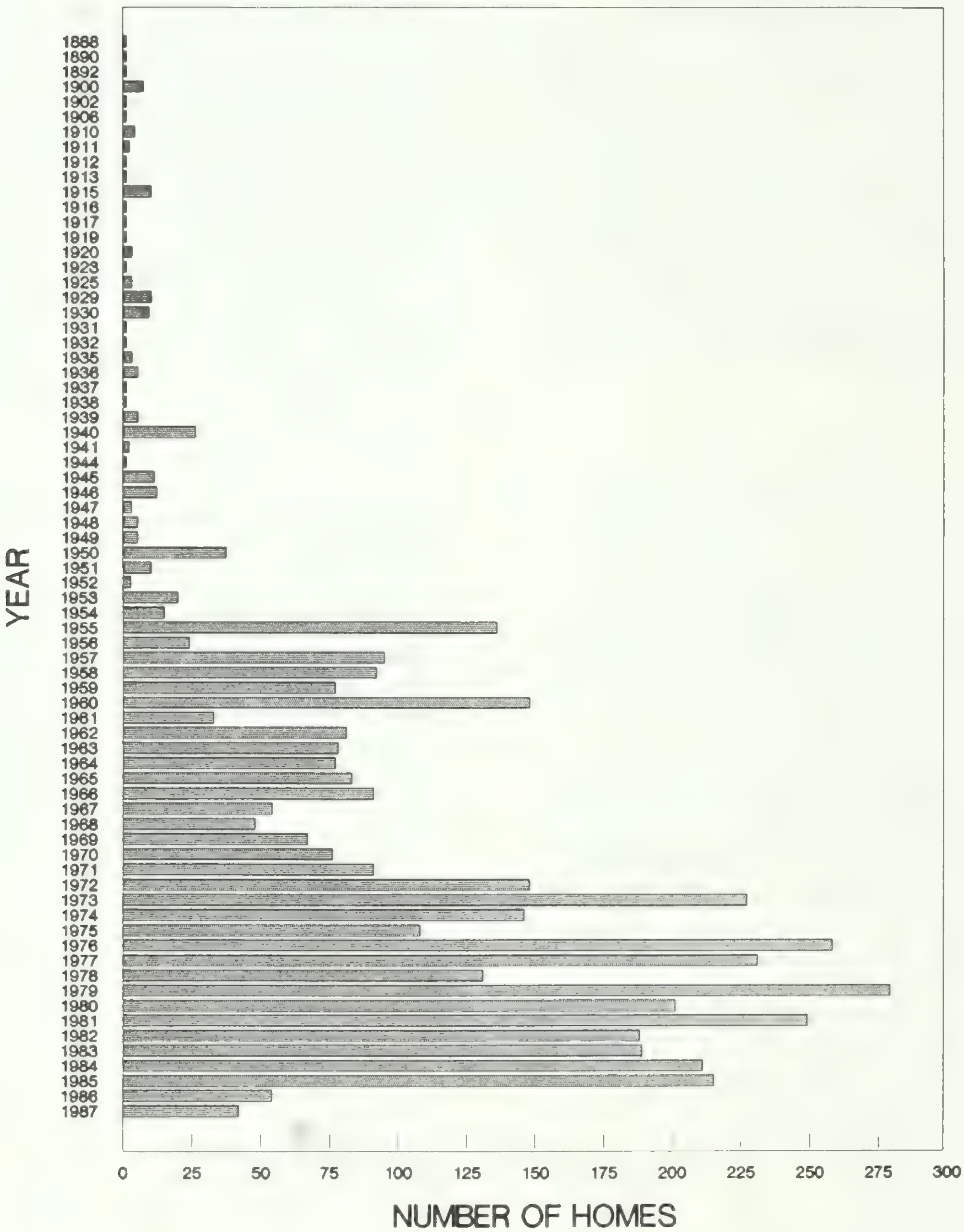

Figure 2.--Trends in residential development within the ponderosa pine type, central Arizona.

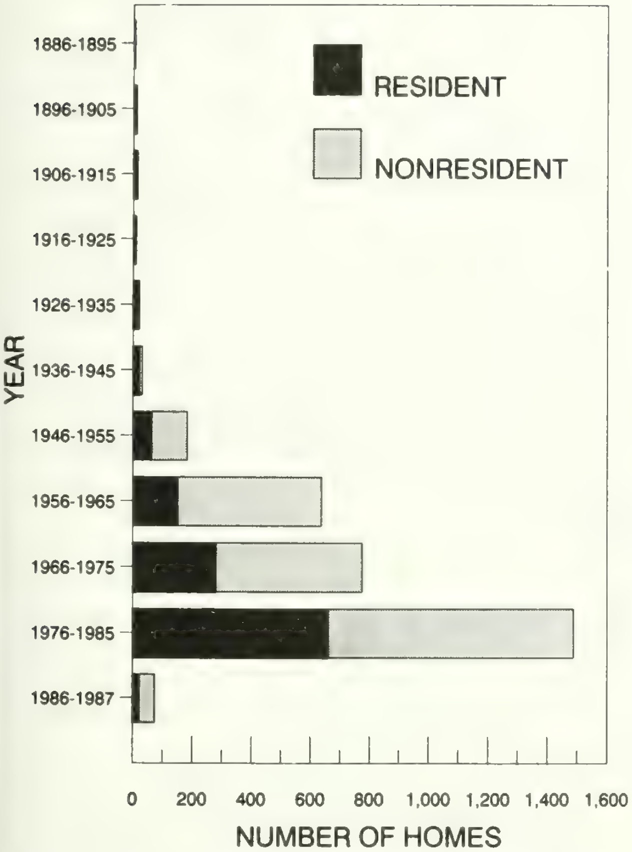

Figure 3.--Trend in home ownership by residents and nonresidents.

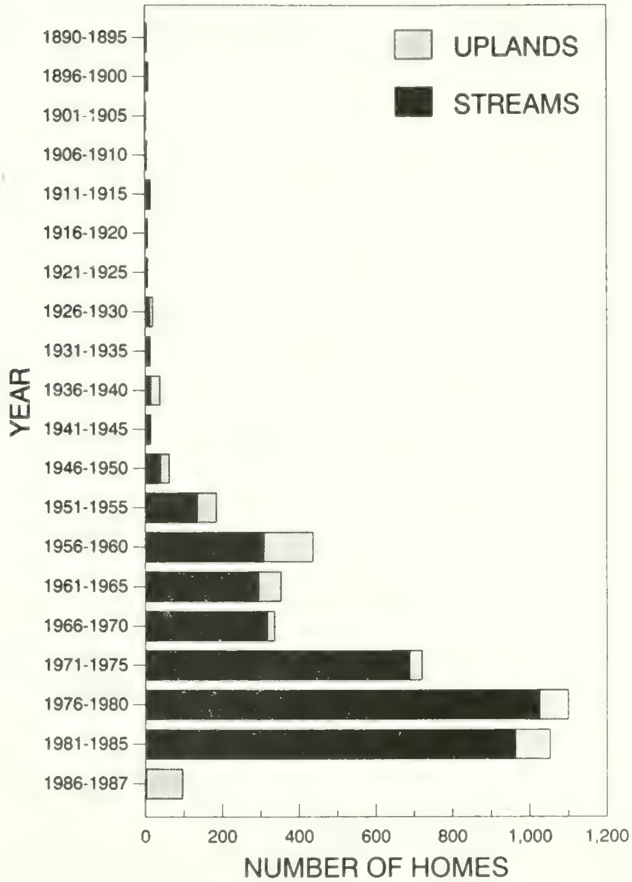

Figure 4.--Trend in residential development along streams and uplands within the ponderosa pine type, central Arizona.

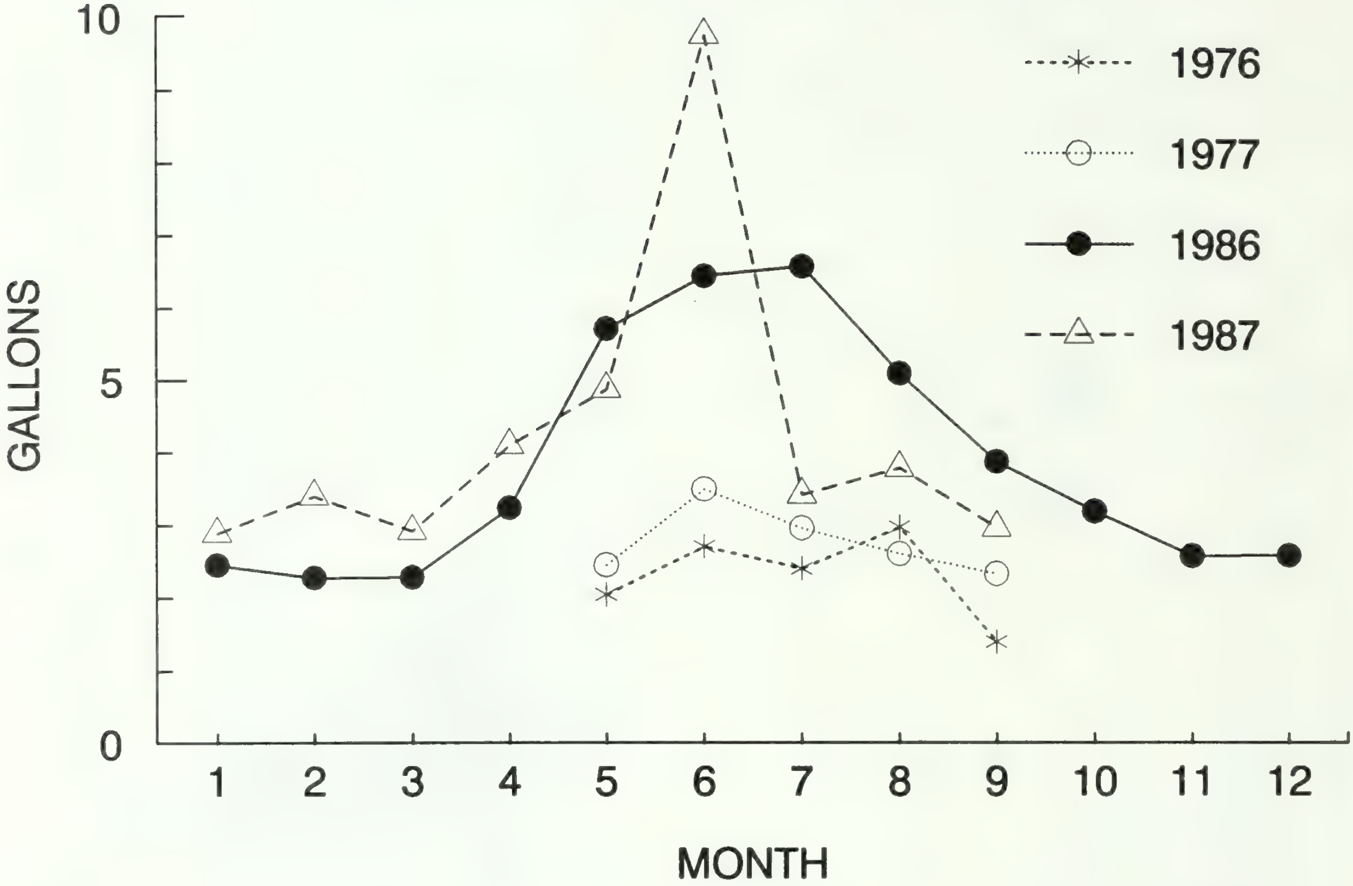

Figure 5.--Trend in water usage for the community of Pine.

stream and ground water quality may deteriorate because of vegetation and soil disturbance (Grant and Lewis 1976), which may result in increased surface runoff (Trotta 1979).

CONCLUSIONS

Home development rates have spiralled since the mid-1950's in the Pine area and the region below the Mogollon Rim. Increased demand for domestic water has paralleled home development to such an extent that development has declined due to the unavailability of water. In the community of Pine, for instance, consumption rates exceeded the amount provided by stream base flows. Water demands are greater during the summer because summer residency increases 2 to 3 times, but a greater potential exists for future water shortages because about 47% of private lands remain unsubdivided and about 50% of subdivided lots remain undeveloped.

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Multiresource Management, Decision Support Systems, and Expert Systems: Moderators' Comments

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Multiresource forest management is by definition an interdisciplinary activity. Few forest managers, in this age of specialization, have the expertise to fully evaluate the enormous range of potential multiresource impacts associated with forestry activities such as timber harvests, range improvements, or recreation developments. The difficulty of making such evaluations, in fact, was one of the central arguments that was made in earlier times in favor of developing single-resource forest management plans rather than a single, comprehensive multiresource forest management plan.

The development that represents perhaps the greatest single advancement in bringing the practice of multiresource forest management closer to reality is the computer, and especially the personal computer. For the first time in history, scientists involved in multiresource forest management research can be assured that personnel involved with the everyday practice of forestry have available to them powerful computing capabilities that permit immediate access to enormous databases, virtually instant calculations, and the rapid preparation of graphical results that can improve both communication and decision making, and can also reduce the chances of interpretation errors.

Much of the research that is currently underway relating to the practice of multiresource forest management involves the use of computer technology by interdisciplinary teams, simply because of the sheer difficulty of comprehending all of the interrelationships inherent in forest ecosystems. The six papers in this session explore several aspects of computing technology as related to the practice of multiresource forest management. The first three papers consider the Terrestrial Ecosystem Analysis and Modeling System (TEAMS), a multiresource forest management decision support system developed by the School of Forestry at Northern Arizona University. The paper by Covington and his colleagues explains the foundations of the TEAMS model; the papers by Wood and others and by Fox and others then report on experience using the model as a tool to improve project-level planning by the Navajo Forestry Department and by the USDA Forest Service.

The remaining three papers in this session consider several independent but interrelated subjects that are important to multiresource forest management. The paper by Tecle and his colleagues discusses methodologies for resolving conflicts in forest planning through the use of multiobjective decision analysis. Long and Wagner then report on an effort to develop a microcomputer-based expert system for insect pest management decision making. Finally, Patton and Severson discuss the use of a relational database coupled with artificial intelligence software to improve retrieval of information related to wildlife habitat relationships.

Current Status of the TEAMS Decision Support System: Structure, Development, and Application[1]

W. Wallace Covington, D. Brent Wood, Aregai Tecle, and Bruce E. Fox[2]

Abstract: TEAMS (Terrestrial Ecosystem Analysis and Modeling System) is a computer based decision support system designed to aid in developing site specific treatment alternatives. TEAMS combines a geographical information system, a multiresource simulation model, an optimization module, and a graphics output display package, all organized around a relational database management system. TEAMS has been used to develop treatment plans for timber sales and multiproject, watershed level management units. These applications, as well as use in teaching, have led to identification of potentially useful design and operational improvements in decision support technology. These enhancements are in the areas of remote sensing technology, geographical information systems, simulation models, automated goal seeking, and conflict resolution procedures.

INTRODUCTION

A central problem confronting public forestry today is how to efficiently implement forest level land management plans while fully addressing both short and long term environmental consequences of a full range of management alternatives. Furthermore, because treatment location must be considered with respect to other ecosystem patches, surface water sources, topographic position, and road and trail systems, spatial pattern of treatments is also crucial. Thus both temporal and spatial changes must be included in the analysis.

Despite the longstanding recognition of the necessity for taking a systems approach for accomplishing this task, there has been an alarming lack of practical procedures and technologies for implementing integrated multiresource management on the ground.

For national forests, forest plan implementation means selecting, scheduling, and administering management practices that meet forest plan direction as well as the requirements of both the National Forest Management Act (NFMA) of 1976 and the National Environmental Protection Act (NEPA) of 1969. Thus forest plan implementation (USDA Forest Service 1987) involves:

1. identifying feasible management practices;
2. analyzing and evaluating the short and long range consequences of feasible actions;
3. deciding upon an appropriate course of action;
4. developing budgets;
5. executing and administering projects; and
6. monitoring and evaluating the results of the activities.

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[1]Paper presented at the Multiresource Management of Ponderosa Pine Symposium. Flagstaff, AZ. November 14-16, 1989.

[2]W.W. Covington and D.B. Wood are professors, A. Tecle and B.E. Fox are assistant professors, School of Forestry, Northern Arizona University, Flagstaff, AZ

A conceptual framework for integrated analysis is available in several publications which detail a stepwise procedure for analysis and documentation in support of land management plan implementation (e.g., Jameson and others 1982, USDA Forest Service 1988). However, interdisciplinary teams trying to follow such procedures have found it all but impossible to fully address the temporal and spatial consequences of a broad range of management scenarios. There has been a widespread hope that the acquisition of geographical information systems (GIS) technology will go a long way toward alleviating this problem. However, GIS is far from a panacea. Although its utility in map based information management, analysis, and display is unquestionable, GIS alone deals only with current conditions.

A mechanism for is needed for generating a full range of treatment possibilities, forecasting their temporal and spatial consequences, narrowing the treatment possibilities down to those which meet overall management criteria, and finally choosing the best of these possibilities. Such an analysis done manually would require an inordinate amount of time. Computer automation can accomplish many of the tedious steps in such an analysis and, if used in conjunction with a systematic, stepwise interdisciplinary team process, it can greatly facilitate forest plan implementation.

This paper is presents an overview of the complex nature of implementing multiresource management, to describe a computer aided approach for assisting interdisciplinary teams in using the vast array of information needed to accomplish the task, and finally to suggest some further development needs with respect to decision support for integrated resource management. The examples and terminology we will use will be most familiar to those involved in national forest management issues, but we believe that the concepts are generally applicable to other public natural resource management situations.

COMPLEXITY OF IMPLEMENTATION

Implementing multiresource management is a complex, information intense task. To begin with, the interdisciplinary team must know the current condition of the management area being considered. For example, if the area being considered has current or potential use for timber harvesting, wildlife habitat, downstream water use, recreation, and livestock grazing, then the interdisciplinary team must have information on such resource condition indicators as density, vigor, and species composition of both trees and understory vegetation, watershed condition, water availability, transportation system condition, current wildlife habitat use, current recreation use, and so forth. Furthermore, this information must be referenced to specific locations within the management unit so that questions regarding landscape interactions, resource access, and so forth, can be addressed.

Next, the interdisciplinary team must assess treatment suitability for each ecosystem patch (which are perhaps 30-100 acres), including of course a no treatment option. In the case of timber harvesting, the management unit would be a stand. Then, for each feasible management scenario, the team must forecast both short and long term consequences for the various resource condition indicators for each management unit, as well as for the management area as a whole.

After having generated all of this information, the next step involves narrowing the choices down to some subset which meets the standards and guidelines specified by a land use plan and achieves the goals and objectives for the specific management area. The next task is to prepare documentation detailing the procedure and logic used to develop a full range of management scenarios and the tradeoffs among them; this documentation is then used by a manager to make a decision as to how to manage the area in question and to meet NFMA and NEPA requirements. Finally, treatments are implemented, monitored, and evaluated to compare what actually happened with what was anticipated.

Throughout this process it is incumbent upon the interdisciplinary team members to use the best available knowledge and procedures and to keep a detailed record of what occurs at each step in the analysis.

What actually happens today is a far cry from this. Some reasons for this are obvious. Typically, time is limiting and so are the number of individuals who can devote their full attention to the task in a team setting; scheduling meetings which most of the team members can attend often seems to be a insurmountable problem.

A more fundamental problem is how to cope with the tremendous amount of information needed in the analytical process. Furthermore, the complexity of the analytical task is such that tracking and understanding the logic behind the results and recommendations is practically impossible.

Automation of some of the more tedious parts of this procedure provides a mechanism for making the problem more tractable. Several types of software are available which can be used to solve parts of the overall problem. Geographical information systems facilitate spatial analysis, simulation models forecast growth and yield of trees and other resource conditions for various alternatives, heuristic software aids in developing decision rules for treatments to be considered, mathematical programming models facilitate automated goal seeking, database management systems allow rapid retrieval of information, and graphics output software can create displays which summarize the data so that it can be readily understood. However, analytical efficiency can be greatly improved by linking appropriate software modules to form an integrated decision support system. One such system, operational for southwestern ponderosa pine, is the TEAMS decision support system (Covington and others 1987, 1988).

STRUCTURE OF TEAMS

TEAMS is a general integrated decision support system framework for facilitating the analysis and interpretation necessary for comprehensive forest plan implementation. Currently TEAMS is designed for analysis of management areas ranging in size from a few thousand to tens of thousands of acres. It is intended to assist those concerned with project design and implementation in dealing with the complexity of multiresource ecological, economic, and political information in a integrated, iterative fashion.

Current versions of TEAMS (fig. 1) include a geographical information system, a multiresource forest activity simulation model, a mathematical programming model, a database management system, graphics output software, and the software which links them all together. Although the TEAMS concept could be used to integrate a wide variety of software, only the following module are currently being used:

1. Geographic information system -- ESRI's ARC/INFO and TYDAC Technologies' SPANS
2. Forest activity simulation model -- ECOSIM (Rogers et al. 1984)
3. Database management system -- Microrim's R:BASE
4. Graphics output software -- Microsoft's CHART

TEAMS projects outcomes of treatment alternatives and displays results in graphic, tabular, and map forms. With these results, managers may develop and test other treatment alternatives in response to perceived problems and opportunities. Thus TEAMS is an interactive tool that ultimately relies upon human judgement and expertise throughout the management process. Its function is to provide interdisciplinary teams with rapid feedback on the likely consequences of management alternatives being considered.

When using TEAMS, the primary unit of analysis is the stand, which is defined as a contiguous area which is relatively homogenous in terms of site quality and tree structure, age class, and density. Currently, stand-level alternatives consist of various harvesting and thinning options. The model also processes alternatives at the management unit level (as opposed to the stand level), including recreational developments and range improvement options.

Several versions of TEAMS have been developed. One version, for example, is designed to assist in the development of a 10-year annual treatment schedule and projects annual outputs for years 1 through 20. Another is designed for a 30-year treatment schedule by decade and projects outputs in 5-year increments through year 50. Each version has been customized to meet the concerns and needs for the particular problem being addressed.

TEAMS may be used in three ways. First, managers may directly specify how each stand within the management area should be treated. The system will then project and display on a computer screen, or in printed or plotted format, the predicted results of the prescribed treatment schedule that the managers can subsequently compare to goals, standards, and guidelines. Alternatively, managers may specify goals, standards, and guidelines for the unit, and TEAMS will

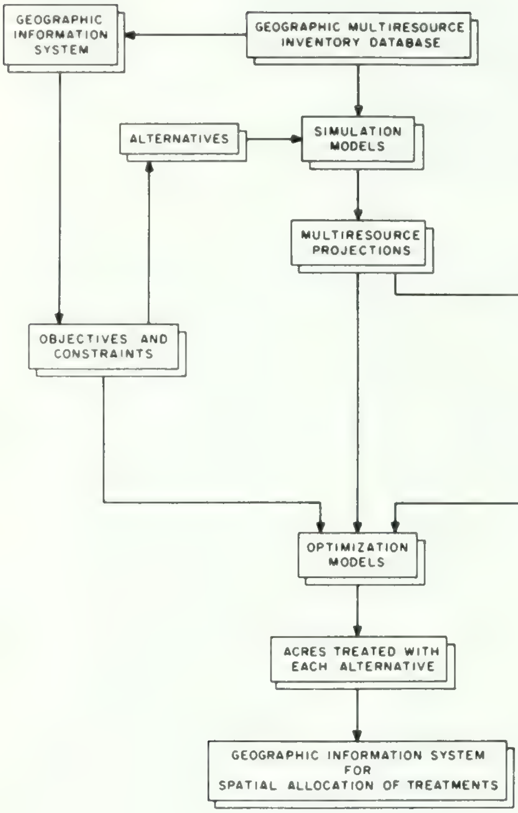

Figure 1. Flowchart for TEAMS decision support system

produce an optimal treatment schedule and project results. Finally, a combination of the first two approaches may be employed with prescriptions for some stands specified by the managers and others determined by the system. Regardless of the option chosen, management teams can use an evolutionary approach by making a series of computer runs, examining the output, and revising run conditions until they are satisfied with the overall design of the management regime. More detail regarding the structure of TEAMS is available in Covington and others (1988) and Covington and Wood (1989).

USE OF TEAMS

TEAMS has been used in support of forest management implementation analyses for multiresource management of ponderosa pine in Arizona, including timber sale analysis (Fox and others 1989) and multiproject and watershed level analyses on the Coconino National Forest (Covington and Wood 1988) and Navajo Nation forest lands (Wood and others, this volume). It has also been used to facilitate teaching multiresource management concepts and procedures at both the graduate and undergraduate levels (Wood and others 1989). These uses have helped to identify opportunities for improving TEAMS to better suit the needs of those concerned with multiresource management.

ENHANCEMENTS IN DECISION SUPPORT

Our use of TEAMS on operational projects, as well as in research, development, and teaching applications, has helped us characterize some desirable features of decision support tools (Fox and others, in press). We will discuss needed improvements under the subheadings of: resource inventory and monitoring; geographical information systems; multiresource simulation models; automated goal seeking models; and conflict resolution procedures.

Resource Inventory and Monitoring

Determining resource status is essential for planning, monitoring, and evaluation. Recent advances in remote sensing technology, in conjunction with GIS developments, provide opportunities for increasing the efficiency of resource inventory and facilitating monitoring and evaluation. Multistage sampling and analysis procedures which take advantage of the increasing resolution of satellite imagery supported by a combination of aerial photograph interpretation and field checking promise to provide resource managers with efficient methods for acquiring inventory information. These same techniques, used in conjunction with image processing procedures designed for detecting changes over time, can provide a mechanism for monitoring and evaluating the many treatments implemented on the management area. Thus remote sensing technology can go a long way toward meeting decision support needs. At the early stages of forest plan implementation this technology can provide information on current resource status and at the final stages it can be used for detecting changes in resource conditions for feedback in the monitoring and evaluation process.

Geographical Information Systems

A major enhancement in decision support software is needed in the GIS arena. It has become increasingly apparent to us that in addition to a centralized, highly technical forest-wide GIS, an independent GIS in each management unit (district office) is essential. Such a GIS should be user friendly and efficient so that individual interdisciplinary team members can explore geographical databases, generate treatment suitability models, and display the results of such models. After treatment scenarios have been developed the interdisciplinary team members should be able to use the GIS to display the future consequences of these scenarios.

Network modeling must be an essential feature of the GIS so that the ID team can deal with such problems as wildlife habitat fragmentation, wildlife travel corridors, treatment suitability, and trail and road system design.

Multiresource Simulation

A central limitation to implementing multiresource decision support systems is the lack of multiresource forest management simulation models. Currently, such software is available only for southwestern forest types (Rogers and others 1984), although it is being developed for other types.

A major stumbling block to developing such models is the lack of data needed to develop and calibrate them. Although tree growth and yield models are available for the major forest types in North America, there is a scarcity of models which predict the consequences of forest management on wildlife, recreation, watershed conditions, and range.

One promising method for developing such models from existing knowledge is the modeling workshop technique developed by Holling and Walters and their colleagues at the University of British Columbia (Holling 1978, Walters 1986). This technique, called Adaptive Environmental Assessment, brings people from a wide variety of backgrounds and with a broad mix of knowledge and talents together for brief periods of intense interaction to develop models to be used in resolving resource management problems. Participants typically include a modeling team, research scientists, resource managers and specialists, policy analysts, decision makers, and key representatives of those groups concerned with the outcome of the decision process. The goal is to develop and test a quantitative model of the management problem within the limited time available. An example of application of this procedure to a multiresource management issue in forestry is the development of SAMM (Southeast Alaska Multiresource Management Model) by Fight and others (unpublished).

To date, few of the models developed by this technique have been used directly as decision support systems (Walters 1986, C.S. Holling, personal communication). Instead, these models have served to promote clearer thinking by, and communication among, the workshop participants about the general nature of the problems being addressed. Nonetheless, the modeling workshop approach could be used to bring together the best available knowledge about systems dynamics to develop models for forecasting the consequences of management activities.

Simulating the impact of forest management on the large number of wildlife species present poses a major challenge. However, combining a relational database with artificial intelligence technology as proposed by Patton and Severson (this volume) seems a promising approach.

Automated Goal Seeking

Once a multiresource simulation model has been used to forecast future conditions for the management unit, the next problem is reducing the vast number of possible treatment scenarios down to those which meet the overall management criteria established by the land use plan and the site specific analysis of specific issues, concerns, and opportunities. Although the most familiar mathematical programming techniques such as single objective linear programming and goal programming can be used to accomplish this task, other techniques such as multicriterion decision modeling procedures which may be more appropriate for multiresource management (Tecle and others this volume) should be explored.

Automated goal seeking software which is currently available is somewhat daunting to natural resource managers and laymen alike. What is needed is user friendly software which leads the interdisciplinary team through the construction of a multiobjective problem formulation which they can fully

understand. This module should also facilitate sensitivity analysis and other gaming with the database.

Conflict Resolution Procedures

A characteristic feature of multiresource management problems is the presence of multiple conflicting objectives that must be resolved (Fraser and Hipel 1984, Tecle and others 1988a, Tecle and others, this volume). A procedure for formulating such problems is provided in Tecle and others (1988b). This includes identifying objectives, specifying criteria, generating alternatives (or decision variables), constructing a feasible region, and determining the best solution within that region. Commercial computer algorithms are available to facilitate the evaluation process (e.g., Korhonen and Laakso 1986, Fraser and Hipel 1988). What is lacking, however, is modular integration of such algorithms into decision support systems such as TEAMS.

Flexible, integrated software for accessing, retrieving, and generating reports on database information coupled with simulation and decision models for conducting further analyses including alternative testing, sensitivity analysis, and automated goals seeking is essential for dealing with issues of the complexity facing us today in multiresource management. Supporting individual human knowledge, reasoning, and common sense of interdisciplinary teams with appropriate computer software to handle the routine, tedious tasks of analysis promises to help us improve the quality of our decisions regarding the public estate.

CONCLUSION

The rapidly exploding technology of digital electronics and software provides a promising avenue for natural resource managers to better achieve integrated forest management. These systems can support and augment human intellect, extending and amplifying mental capabilities. However, computer aided approaches must be user friendly, integrated, and understandable by those with relatively little familiarity with computers. Integrated decision support system software must be developed and implemented as soon as possible. Otherwise it seems certain that attempts at implementing forest plans will be overly time consuming, far from optimal, and difficult, if not impossible to defend.

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Use of a Computer-Aided Decision Support System in Forest Plan Implementation[1]

D. Brent Wood, W. Wallace Covington, Aregai Tecle, Bruce E. Fox, and C. Gordon[2]

Abstract.--A decision support system, TEAMS, has been used to develop stand-specific prescriptions for a 20,000 acre forest management area on the Navajo Reservation. A comparison of TEAMS results with those developed by conventional methods indicated that TEAMS has great potential for improving forest management decisions.

INTRODUCTION

During the past five years, the Northern Arizona University School of Forestry (NAU) has been developing a computerized decision support system (DSS) for multiresource forest management. The School designed this DSS, TEAMS (Terrestrial Ecosystem Analysis and Modeling System), to aid managers in evaluating alternatives in a multiresource environment (Covington et al. 1987 and 1988). TEAMS provides managers the ability to quickly examine the consequences of potential management alternatives. For each alternative, TEAMS provides projections of resource outputs (for instance sawtimber and forage production), economic impacts (for instance present net value and annual costs) and forest structure (for instance amounts and spatial distribution of deer cover and old growth). The system can project the consequences of a specified set of stand level management prescriptions or, given a set of goals and requirements, TEAMS will find the best combination of site-specific prescriptions for those goals and requirements.

The version of TEAMS used in this paper combines a geographic information system (ARC/INFO), a multiresource stand simulator (ECOSIM), a linear programming optimization package (LINDO), and a graphics output display program (CHART) into a system with data handled by a geographically based relational data base management system (INFO). Linkages among these program modules have been automated; data are transferred among modules without the need for human intervention. Users provide inventory data and make decisions where judgement is required. Extensive menus and queries assist users with data input and program operation. For more information on the structure and uses of TEAMS, see Covington et al. (this volume) and Wood et al. (1989).

Following development of a prototype model, we tested it in a series of actual forest resource management applications in order to accomplish the following goals:

1. To establish whether or not projects designed using TEAMS could increase multiresource productivity;

2. To assess the usefulness and efficiency of TEAMS as a practical management tool for land management agencies; and

3. To identify and implement changes and improvements which would enhance the utility of TEAMS for assisting foresters in implementing multiresource management.

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To date we have completed four studies: one timber sale and two watershed management units ("10-K blocks") on the Coconino National Forest and one on a 20,000 acre compartment on the Navajo Reservation. This paper presents the results of the Navajo study.

The Navajo Study

During the fall of 1987, the Navajo Nation Forestry Department and the Northern Arizona University School of Forestry agreed to undertake a cooperative project designed to test the utility of the School's integrated multiresource decision support system as a tool for managing Navajo forest lands. The Navajo Forestry Department (NFD) is responsible for the management of over one-half million acres of commercial timber land (primarily ponderosa pine). The professional staff is charged with providing a long term annual harvest of approximately 50 million board feet to supply a tribal sawmill while maintaining amenity and traditional values important to the tribe. Although timber harvesting and processing provide important economic benefits and employment, the forests also are expected to provide forage for traditional livestock grazing, construction materials for hogans (traditional log dwellings), fuelwood, wildlife habitat, esthetics, recreation, watershed, and cultural values.

The study was conducted on a management compartment for which the NFD had recently completed a cutting plan. They had examined seven alternative plans which focused on wildlife habitat diversity, road costs, and fencing costs, as well as timber harvest volumes, economic efficiency, and sound silvicultural practices. Because TEAMS could simultaneously handle the analyses of all of these factors, project future outcomes of complex management regimes, and provide assistance in identifying an optimal regime, NFD agreed to participate in an analysis of the area using the decision support system. This cooperative effort offered an unprecedented opportunity to compare a decision support system with conventional methods.

METHODS

The study entailed using TEAMS to identify, evaluate, and compare a variety of alternatives for managing a compartment within the commercial ponderosa pine area of the Navajo reservation. It consisted of four phases:

1. Selection of a study area and specification of goals for the area;

2. Modification of the system to reflect Navajo conditions and requirements;

3. Generation and analysis of alternatives; and

4. Comparison of the selected TEAMS alternative with an alternative developed by NFD using conventional methods.

Study Area

The area selected for analysis by NFD was Compartment 19, a 20,000 acre block of ponderosa pine on the Defiance Plateau north of Fort Defiance, Arizona. Compartment 19 contains 96 stands most of which are two-storied. Overstories are predominantly overmature yellow pine (large, old ponderosa pine) with understories generally consisting of immature pine with relatively low densities. The area is a mesa, with most of its acreage on the flat top. Most of the steep slopes bounding the mesa are inoperable for harvesting. Site quality varies from poor to good. A complete set of recent inventory data was provided by NFD and used in the analysis.

The Department's overall goal for Compartment 19 was to maximize present net value subject to the following requirements:

1. A minimum of 15 percent of the compartment was to be maintained in old growth primarily for wildlife habitat;

2. All stands infected with dwarf mistletoe were to be harvested during the first entry;

3. Archeological sites were to be buffered from harvest activity;

4. A minimum harvest of 28 million board feet was required in the first entry;

5. A minimum harvest of 50,000 poles was required during each entry;

6. No harvesting was to occur on slopes exceeding 40 percent; and

7. Wildlife habitat diversity was to be improved with deer as a featured species.

System Modifications

Modifications to TEAMS were required to make it compatible with the unique conditions and management situation faced by NFD. These were implemented in two stages. First, after becoming familiar with the existing procedures and assumptions of TEAMS, NFD developed a preliminary list of needed revisions. NAU incorporated the revisions, executed a preliminary series of TEAMS runs based on the initial set of goals and requirements, and presented the results to NFD in March, 1988. Second, working together, NFD and NAU carefully evaluated the outputs and identified additional system modifications to enhance its utility in evaluating alternatives. Such testing and modification continued until we were satisfied that the system was providing the information required for assessing outcomes according to Navajo criteria.

System modifications were of three general types. First, values and costs specific to the Navajo Nation were substituted for those then in the system. New cost categories were also added for pole marking and for fencing regenerating stands. Poles are provided free of charge for hogan construction, but because of heavy demand, harvest must be closely regulated to avoid degradation of the timber resource. Heavy grazing by sheep, an activity of great traditional importance to the Navajo people, could result in nearly total seedling loss without protection. Because there is no market for pulpwood in the area, pulpwood outputs were eliminated.

Second, stand level treatment alternatives were modified to reflect NFD practices. We altered shelterwood alternatives to conform to NFD silvicultural standards and added thinning alternatives with lower residual basal areas than the existing version of TEAMS was simulating. The model was also altered to encompass three 20-year periods reflecting the 20-year reentry cycle employed by NFD.

The third type of modification involved adding new outputs and growing stock provisions which could be projected, constrained, and displayed along with original outputs. These included pole harvests and standing poles (required for hogan construction), area standards for old growth, number of snags, and future diameter distributions. NFD also requested additional GIS plots showing the locations, types, and times of treatment for each alternative because of concerns for harvesting and transportation efficiency.

Alternative Analysis

Following system modification, the TEAMS analysis began with two baseline runs: one in which no timber harvesting was allowed and another in which present net value was maximized without any other constraints or requirements. Comparison of these runs to constrained ones enabled us to analyze the tradeoffs imposed by requirements for such things as timber harvest level and wildlife habitat. We next added a set of constraints reflecting NFD's initial specification of goals and requirements for the compartment. After TEAMS was run, NFD analyzed outputs, tradeoffs, and opportunity costs associated with these constraints and identified problems and opportunities for improvement.

A number of problems were identified upon examining results of the initial alternative specified by the Department. First, the 15 percent old growth requirement could not be achieved until the third entry of the analysis period. An insufficiency of current old growth and time needed to achieve old growth conditions prevented meeting the requirement. Nothing could be done to eliminate this problem. Second, when compared to the unconstrained maximum PNV run, meeting all of the NFD requirements created an opportunity cost of over $2.7 million. Third, the level of harvest in the first entry exceeded the maximum capacity, 50 million board feet, of the Navajo sawmill. Finally, at the end of the 60 year analysis period, the pole inventory had dropped to near zero. Because continuity in the availability of hogan construction materials is important to the Navajos, this was unacceptable.

Given the results of the first analysis, the linear programming formulation was altered. The excessive sawtimber harvest was prevented by constraining the harvest to a maximum of 50 million board feet. Although this nominally reduced present net value, harvests over this amount could not be utilized and, in reality, would contribute nothing to PNV.

Further analysis showed that opportunity costs could be materially reduced by scaling down old growth requirements and eliminating constraints which would require treatment of mistletoe infected stands in the first entry. Although other requirements generated opportunity costs, only these were deemed discretionary by NFD. Old growth requirements for the first two entries had previously been reduced in order to achieve a feasible solution. The third period requirement, however, still had a significant effect on management and generated high opportunity costs. Reducing the old growth requirement from 15 percent to 10 percent of the total area increased present net value by over $700,000.

Mistletoe infections are ordinarily treated as rapidly as possible through regeneration harvests or heavy thinning of infected trees. Because of the surprisingly high opportunity costs entailed in early treatment ($240,000) and the relatively minor degrees of infection within the compartment, NFD concluded that treatment could be delayed in most cases. Mistletoe treatment constraints were altered accordingly.

Finally, we added a constraint requiring an ending inventory of 500,000 poles following the third and final entry. This constraint did not affect the quantity of poles harvested during the three entries, as feared, but did result in prescriptions which produced more poles.

After making these changes another TEAMS analysis was run and outputs were presented to NFD. After examination, a new list of potential adjustments was compiled and analyzed. This process continued through several iterations. With each succeeding iteration the magnitude of adjustments became smaller and smaller until solutions converged on an alternative which could not be materially improved.

Following the TEAMS analysis described above, NFD provided a complete accounting of prescriptions for stands within Compartment 19 which had been developed independently. These were translated as accurately as possible into the treatment categories employed by the TEAMS system and constraints were written for each stand to "force" TEAMS to select and simulate the NFD prescription as closely as possible.

RESULTS

In discussing results we concentrate on comparisons between the alternative finally selected using TEAMS and the alternative developed independently by NFD.

The silvicultural prescriptions elected using TEAMS differed substantially from those specified by NFD. Table 1 shows that, without TEAMS, NFD had prescribed a much higher proportion of shelterwood harvests than they did using TEAMS. NFD called for shelterwood harvests on nearly half of the compartment (9,424 acres) whereas only about 1300 acres would be regenerated with the TEAMS alternative. Most of the NFD regeneration harvests (6000 acres) were scheduled for the first entry. Because of low stocking rates in many of the stands, NFD reasoned that it would be beneficial to regenerate

Table 1. Summary of silvicultural prescriptions for TEAMS and NFD.

Treatment	Period 1		Period 2		Period 3	
	NFD	TEAMS	NFD	TEAMS	NFD	TEAMS
	(acres)					
Overstory						
Harvest only	4527	5821	--	8249	5002	925
With thinning	1473	3628	196	143	--	--
Total overstory harvests	6000	9449	196	8392	5002	925
Shelterwood						
Seed cut	7093	409	2331	800	--	97
Final removal	--	--	7093	409	2331	800
No harvest	-------------		1025	1952	------------	

as soon as possible in order to increase their productivity, a standard practice. Shelterwood harvests, however, entail leaving a high proportion of the largest trees as a seed source for a 20-year period and generate costs for site preparation and fencing. It was economically better to harvest the overstories immediately and to delay regeneration until the understories reached maturity. The TEAMS analysis showed that losses in overstory value (primarily because of discounting) and high regeneration costs overshadowed values associated with restocking the stands. The two alternatives also differed markedly in the acreage left unharvested. With TEAMS, nearly 10 percent of the compartment would not be harvested, nearly double the unharvested area prescribed by NFD.

Table 2 shows resource outputs and conditions projected by TEAMS for the NFD and TEAMS alternatives. Entries were simulated in Years 1, 21, and 41; activities in Year 61 were limited to final removals on acreage receiving a seed cut in Year 41. Outputs reflect post-harvest conditions.

Volume harvested was higher for TEAMS in the first entry but lower in the second two; total volume harvested was higher for NFD. The numbers and distributions of trees projected for the end of the analysis period (Year 61) were as follows:

Dia. class	NFD	TEAMS
---(in)---	---1000's of trees---	
< 5	473	87
5-12	1122	509
12-16	360	967
16+	116	291

In that year the TEAMS alternative would produce nearly 300,000 mature trees (greater than 16-inch DBH), a number more than sufficient for another sawtimber harvest entry (for comparison, there are currently 238,000 trees of that size in the compartment) whereas the NFD alternative would yield only about one-third that number, too few for harvest given economic considerations and multiresource concerns. NFD produced more poles in the ending inventory.

NFD pole harvests were substantially higher than those yielded by TEAMS during

Table 2. Comparison of results from TEAMS and NFD alternatives.

	Year			
	1	21	41	61
Sawtimber harvest (Mbf)				
NFD	38,059	53,960	33,440	--
TEAMS	50,000	44,675	15,785	198
Pole harvest (1000's)				
NFD	226	207	--	--
TEAMS	50	50	50	--
Forage (AUM's)				
NFD	526	712	908	864
TEAMS	526	572	615	568
Water (ac.ft.)				
NFD	233	250	367	333
TEAMS	233	217	233	183
Deer cover (ac)				
NFD	4,842	5,898	6,733	8,298
TEAMS	6,406	10,221	11,429	13,919
Old growth (ac)				
NFD	--	--	172	185
TEAMS	--	905	2,165	2,735
Costs ($1000's)				
NFD	1,213	1,094	544	--
TEAMS	876	775	296	3
Net cash ($1000's)				
NFD	3,859	6,384	4,054	--
TEAMS	6,052	5,356	1,812	18
Present net value ($1000's)				
NFD	----------- 8,190 -----------			
TEAMS	---------- 10,130 -----------			

the first two entries but fell to zero in the third entry (table 2). TEAMS, however, provided the minimums specified by NFD for all three entries. NFD considered the continuation of harvest into the third period a benefit and determined that the lower harvests in the first two entries would be balanced by economic gains. Increasing pole harvests would have been expensive in terms of marking and administrative costs as well as limiting opportunities for more profitable management alternatives.

Although both NFD and TEAMS produced increases in forage yields (table 2), those for NFD were substantially higher. Water yields for TEAMS declined in some periods and were lower than those projected for NFD in all but the first period (table 2). Although high levels of forage and water were considered desirable, when tradeoffs in economic values and provision of other resources were considered, NFD judged the smaller yields reasonable. Achieving higher levels would entail substantial economic costs in timber management, deplete growing stock available for future harvests, degrade deer habitat, and nearly eliminate old growth.

Deer habitat is currently limited because of insufficient cover acreage. Cover would remain inadequate with the NFD alternative whereas TEAMS produced a significant increase (table 2). Figures 1 and 2 show the spatial distribution of forage and cover in Year 21 for NFD and TEAMS, respectively. TEAMS not only provided more cover than NFD but distributed it more evenly across the compartment. (With TEAMS, the user may specify constraints which require cover distribution.) Although the Navajo plan produced more forage, another important component of deer habitat, abundant forage will not be utilized when adjacent cover is lacking. Old growth, which is important for other wildlife species, would be minimal under NFD but was substantially increased (to meet Navajo goals) with TEAMS.

Finally, TEAMS produced a substantially higher present net value (PNV) than did NFD. PNV for the compartment with TEAMS was $10.13 million, an increase of almost 24 percent over the NFD's $8.19 million PNV. There are three major reasons for the increase. First, costs were substantially lower in all three entries (table 2). This was due to lower regeneration costs (fencing and site preparation) and lower pole harvest administration costs. Second, although NFD prescriptions resulted in a higher total net revenue during the planning period, despite higher costs, first entry net revenue was considerably higher for TEAMS (table 2). After discounting future net revenues at 4 percent, TEAMS provided a substantial economic advantage. Finally, ending inventory value, a factor included in PNV calculations, was greater for TEAMS because of the much higher proportion of valuable mature trees remaining at the end of the planning period.

DISCUSSION

Conducting an area analysis on a large multi-stand compartment using conventional methods is a highly complex, tedious, and time-consuming process. Such analyses typically require months of

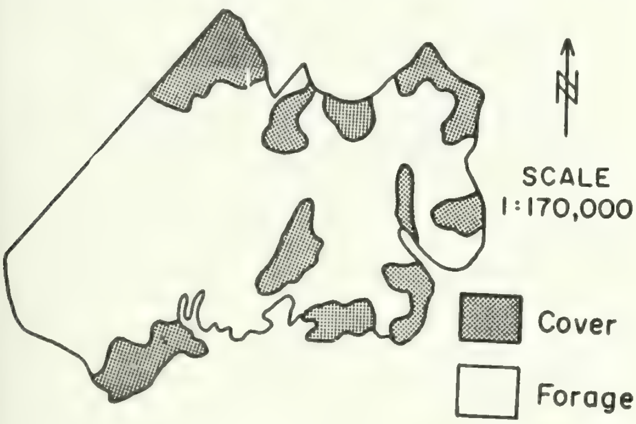

Figure 1.--Spatial distribution of deer cover and forage in year 21 for NFD prescriptions.

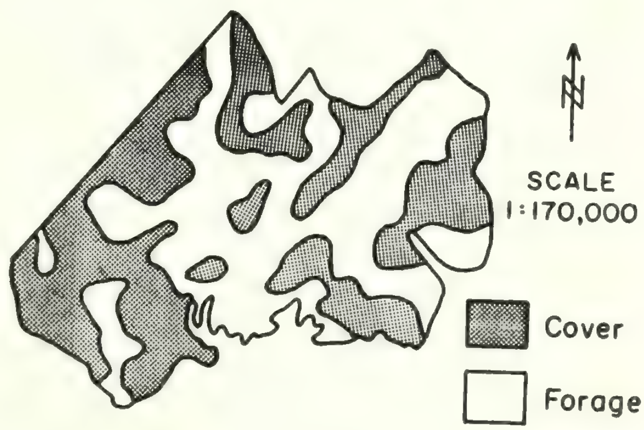

Figure 2.--Spatial distribution of deer cover and forage in year 21 for TEAMS prescriptions.

work and ordinarily only four or five alternatives can be evaluated. Furthermore, it is generally impossible to forecast long-term or cumulative effects in such alternative analyses. At best, planners are only able to assess immediate post-treatment impacts. The complex dynamics of forest ecosystems and vast amounts of information that must be processed make forecasting multiresource impacts exceedingly difficult with conventional computer support. Long term analyses are usually limited to the timber resource and, very often, such analyses employ aggregated data so that results lack spatial definition. Given these difficulties, planners and managers are forced to rely on standards and guidelines which prescribe activities which may and may not be implemented. Rotation limits, adjacency rules, density standards, and regeneration requirements, for example, are imposed in hopes that they will result in desired future conditions. It would indeed be fortuitous if such planning resulted in an optimal solution.

As demonstrated in the Navajo project, computerized decision support systems such as TEAMS can solve many of these problems. First, a large number of alternatives can be analyzed in a relatively short period of time. Over 30 alternatives were tested during this project before arriving at a final decision. The average amount of time spent in computer input and processing was less than an hour per alternative. Furthermore the linear programming element used in the DSS approach allows users to converge quickly on the feasible decision space so that time is not wasted on the nearly limitless number of unacceptable alternatives. Two or three base runs can establish the bounds of possibility for the most important resources. Using TEAMS appears to materially reduce the total time required to formulate and analyze alternatives.

Although initial inventory data entry and digitizing are time-consuming, data acquisition was facilitated in this project because much of the necessary data had been computerized and spatial data digitized by NFD prior to the inception of the project. Transferring and reformatting these data were accomplished through simple computer routines. Because computerized databases are so commonly used by land management agencies, our experience with the NFD should not be considered unusual. Other data, however, had to be extracted from various Department records and hand-entered to the system. Because data requirements are similar for conventional and DSS methods, data acquisition and compilation costs probably do not differ greatly. The real advantage with DSS is its ability to utilize the data more efficiently and productively.

Second, DSS technology allows an efficient incremental approach to decision-making. With this project, we found that each alternative tested revealed problems and opportunities which led to ideas for formulating the next one. Our knowledge of tradeoffs grew with each iteration and by the time we were through experimenting we felt confident in our decision. This approach, we believe, is likely to lead to better decisions than would formulating several discrete alternatives in advance and testing each independently, a common practice. Resource managers commonly fear that utilization of complex computer software will replace professional judgement and experience and cause them to lose control of planning and decision-making processes. We found the opposite to be the case; TEAMS greatly increased opportunities for experimentation and creativity. Instead of depending upon accepted conventions, we were able to examine and evaluate innovative management strategies. Each member of the planning team had the opportunity to try out his ideas.

Third, the multiresource simulation feature of TEAMS allowed us to both examine and constrain the long-term effects of management actions. Projections of future resource outputs and forecasts of both quantitative and spatial elements of forest structure were provided by the system. We were able, for example, to determine that the ending inventory of poles was insufficient to meet future needs and subsequently to add a constraint to ensure that these needs were met. Likewise, we were able to ensure that old growth requirements were met, insofar as possible, both throughout the analysis period and within the ending inventory in the most economical manner.

Finally, the system provided a wide array of information in easily interpreted graphic and map formats similar to the figures provided in this paper. Results from up to four alternatives at a time could be displayed and compared, resource by resource, on a single graph or map set making tradeoff analyses simple.

We are convinced that decision support systems like TEAMS have great

potential for improving multiresource management on Navajo forests as well as other ownerships. However, we also recognize the limitations of the system. The primary result expected from this study was, in fact, a list of problems and needed improvements. We were less concerned with the absolute results than with making TEAMS more useful to managers.

Several needs were identified. First, resource response functions (for projecting resource outputs) need to be calibrated for local conditions. We felt that those currently in the system were sufficiently accurate to demonstrate usefulness but that localization could improve reliability. Multiresource simulation models also need to be developed for other forest types; a model for pinyon-juniper woodlands, which are particularly important to the Navajos, is currently in initial stages of development.

Second, methods need to be developed for dealing with heterogeneity within stands. The simulation models within TEAMS assume homogeneity. Some stands within the study area, however, were diverse enough that a common treatment could not logically be applied to the entire stand. For example, some stands contained dense clumps of young trees as well as patches consisting only of mature timber. These situations, which occurred relatively frequently on the study area, were reflected in NFD prescriptions which specified thinnings in the former and regeneration harvests in the latter. These options could not be directly simulated by TEAMS and hence unrealistic prescriptions resulted. Possible solutions range from subdividing such stands into more homogeneous elements prior to the analysis, to making post-analysis adjustments where necessary. Experimentation is needed to determine the best approach.

Third, the DSS must be customized for particular applications and users. The Navajos, for instance, required a continuing supply of poles. Providing sufficient flexibility within the model to make it universally applicable would be essentially impossible. Fortunately, the modular design of TEAMS makes such changes relatively simple.

Fourth, methodology is needed for coordinating the management of a compartment in time and space with the forest unit of which it is a part. Optimizing each compartment in isolation will seldom, if ever, result in optimal management for the forest as a whole. On the other hand, comprehensive, long-term forest planning on a site-specific basis is clearly impractical, and probably impossible, with current technology. The NFD, like other agencies, must currently rely on subjective, intuitive techniques for bridging the gap between long term strategic planning and project level implementation. The Navajos, for example, have established an annual sustainable harvest of approximately 50 million board feet through their long term planning process. Once general harvest locations are established, a DSS like TEAMS can help to develop optimal site-specific strategies for attaining harvest targets and meeting other multiresource goals within the selected compartment(s). Determining the sequence in which compartments should be entered over time (i.e., which compartments should be entered in years 1, 2, 3, 4, etc.), however, is an important issue. An intermediate level of planning, we believe, is needed to establish this order of entry based on such things as economic efficiency, interactions among compartments, and transportation system development.

Finally, to be of maximum utility to managers and planners, the system must be usable with a minimum of technical training. Much efficiency and creativity is lost when analyses must be routed through and interpreted by a computer expert. We have designed TEAMS with this goal and many of its capabilities can be accessed with relative ease. Other features like most contemporary geographic information systems, however, still require substantial technical expertise. System operation needs to be simplified before it can utilized without technical support by agencies like NFD.

FUTURE PLANS

Based upon the promising results of this study, the School of Forestry and the Navajo Forestry Department have jointly developed a proposal designed to solve the problems and implement the improvements we have identified. The project, which we expect to begin in 1990, is designed to provide a DSS based, hierarchical forest planning system for the Navajo Nation. The system will be designed to incorporate Navajo goals, requirements, and constraints and will encompass all major forest and woodland ecosystems within the Navajo Reservation. The proposal also provides for training

in DSS use and NFD ownership of all necessary hardware and software. We believe that the DSS technology developed during this project will be adaptable to other ownerships and forest types.

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The Effect of Planning Unit Size on Implementing Forest Plans[1]

Bruce E. Fox, D. Brent Wood, W. Wallace Covington, and Aregai Tecle[2]

Abstract: The pattern and magnitude of resource flows over time, as well as the direct and opportunity costs, associated with implementing forest plan standards and guidelines at an operational, on-the-ground level, may depend on the size of the planning units under consideration. As a preliminary examination of this problem multiresource analyses were performed on different sized planning units within the same ponderosa pine dominated watershed in northcentral Arizona, using a computer aided decision support system. Results of these analyses are reported, as well as a preliminary assessment of the relative efficiencies, opportunity costs and tradeoffs associated with implementing forest plan standards and guidelines for different sized planning units.

INTRODUCTION

The National Forest Management Act of 1976 (NFMA) required detailed planning on all National Forests, with the objective of managing the forests to provide for multiple use and sustained yield in the production of goods and services from the forests while at the same time accounting for the environmental impact of management as required by the National Environmental Policy Act of 1969. As a result of the passage of the NFMA, the planning process required for the USDA Forest Service has increased in complexity.

This increased complexity stems from many sources, including requirements for public involvement in the development of forest plans, the use of intricate computer-based planning models, the development of detailed standards and guidelines for management, and provisions in the planning process for monitoring outputs over time. Forest plans have been written for each National Forest, and are beginning to be implemented. This implementation requires the disaggregation of forest level output targets, and the development and application of management treatments to specific units of land.

Given individual forest based plans, a decision is required as to the appropriate size of a unit of forest land on which to apply forest plans. This decision depends on planning scope and objectives and the particular type of resource under consideration. For timber management, the appropriate sized unit might be an individual stand, a group of timber stands, a watershed, a district, or the entire forest. For wildlife management, the size of a planning unit depends both on the wildlife species under consideration, the characteristics of its habitat, and the spatial distribution of this habitat. A watershed planning unit

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could vary from a first order drainage to a major river basin. Likewise, a recreation planning unit could be relatively small and very specific, such as a developed recreation site, or large and fairly general, such as a wilderness area. Economic considerations also influence such disaggregation decisions. For example, the costs of developing transportation and harvesting systems can vary greatly with the size of the planning unit (Davis and Johnson 1987).

In timber management the individual timber sale has long been the traditional unit for implementing forest plan management activities. However logical for timber harvesting, timber sales are not necessarily the appropriate size unit for managing and monitoring the impacts of specific management treatments on other forest resources. In an attempt to address the issue of planning and monitoring units that can vary by resource, the Southwestern Region of the Forest Service (Arizona and New Mexico) is considering a number of options. Some analyses are still being carried out at a timber sale level, while others are being conducted on multi-sale areas commonly known as "10-K Blocks."

A 10-K Block is a contiguous unit of land, approximately 10,000 acres, that is defined by watershed, topographic, or administrative boundaries. Blocks can contain multiple timber sale areas, and sale boundaries may overlap Block boundaries. Forest wide management standards and guidelines are to be applied on each 10-K Block during the implementation process. Planning on 10-K Blocks is driven by the need to achieve Forest Plan resource output targets while adhering to Plan standards and guidelines. In commercial forest types, timber sale activities often serve as the catalyst for planning and implementation efforts.

Previous work in the area of the hierarchical nature of ecological systems, and the effect of hierarchies and planning unit size on Forest Plan implementation, has received considerable attention. Descriptions and discussions of the hierarchical nature of landscapes can be found in Allen and Starr (1982), Allen and others (1984), and Naveh and Lieberman (1984). Concerns over the impact of the hierarchical nature of forest systems, both ecological and organizational, on the Forest Planning process has been raised by numerous authors (Cortner and Schweitzer 1983, Keller 1986, Ryberg and Gilbert 1986, Armel 1986, Merzenich 1986, Milne 1987, and Schugart and Gilbert 1987). The effect of planning unit size on potential timber output levels has been discussed by Hrubes (1976).

Examples of implementing Forest Plans have focused on both methodologies (Ryberg and Gilbert 1986, Dykstra 1987) and the effect on resource outputs when applying Forest level standards and guidelines to a specific land area (Fox and others 1989). The objective of the research reported here was to integrate the concerns about the hierarchical nature of forest systems by comparing resource outputs over time when Forest Plan targets are disaggregated to two different sized planning units, the individual timber sale and a 10-K Block.

METHODS

Accomplishing the research goals required a three step research procedure:

1. Identification of a 10-K Block study area that contained multiple timber sales;

2. Analysis of resource outputs over time for the entire 10-K Block; and

3. Analysis of resource outputs over time for individual timber sales within the 10-K Block.

Study Area

The Bar M 10-K Block on the Mormon Lake Ranger District of the Coconino National Forest in northcentral Arizona was chosen as the study area. This site was chosen for analysis for three reasons. First, inventory data for the Block were relatively recent and complete, aiding in the analysis. Second, the Forest Service had scheduled timber sales and generated output targets for the Block. And third, the arrangement of timber sales within the Block lent itself to a fairly straightforward comparison between outputs for the Block as a whole and the sum of the individual timber sales.

This 10-K Block located 30 miles south of Flagstaff, Arizona, contains 15,901 acres of primarily ponderosa pine forest (fig. 1). The Block has gently rolling terrain overall, but with steep slopes along drainages with

intermittent streams. Elevations in the Block range from approximately 6,500 to 7,500 feet.

At the time this analysis was conducted, the Bar M 10-K Block included five timber sales. Four of these sales, Bar M, Brolliar, Cracker, and Long, are totally contained within the Bar M 10-K Block. Only 1,276 of the 5,184 total acres of the fifth sale, Tie, is contained within the Bar M Block, with the remaining acres of this sale in an adjoining 10-K Block. The Bar M 10-K Block is subdivided into 401 individual stands ranging from 2 to 285 acres. Site indices range from less than 47 to over 90. Timber volumes per acre range from 0 in open meadows and parks to over 37 thousand board feet (MBF) (table 1). No timber has been cut in the Block for over 40 years.

Since only part of the Tie Sale is located within the Bar M 10-K Block, the targeted harvest for this sale (13 MMBF) was not included in the analysis. To prevent harvesting in the Tie Sale area from contributing to the overall Block timber output, constraints were specified to prevent harvesting in all stands in the Tie Sale. Other resource outputs from the Tie Sale that would

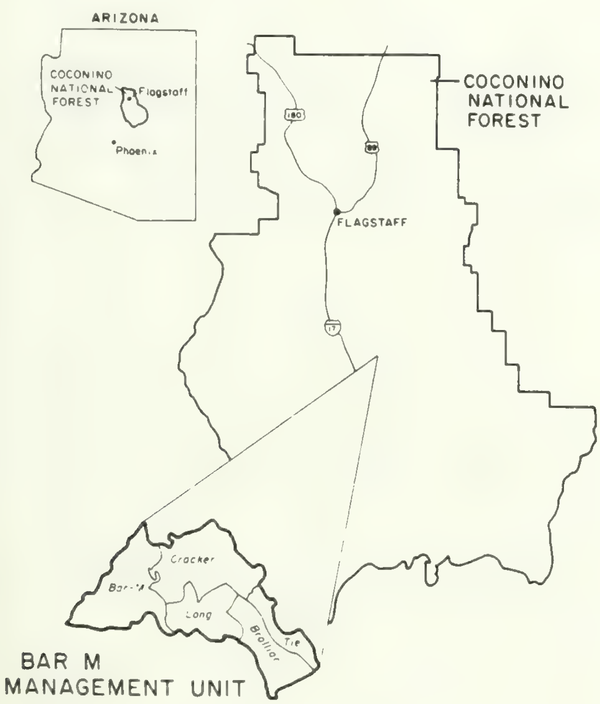

Figure 1. Location of Bar M 10-K Block and individual timber sales

occur in the absence of harvesting were allowed to contribute to overall output totals, however. All non-timber outputs for the Tie Sale were also included in the combined totals for the individual sales to insure comparability between the individual sale and 10-K Block analyses.

Only general Forest Plan standards and guidelines were considered in this analysis. Specific issues, concerns, and opportunities associated with the Bar M 10-K Block, such as Spotted Owl habitat, were not considered in this analysis.

10-K Block Analysis

The multiresource analyses of alternative management prescriptions for both the Bar M 10-K Block and the individual timber sales within the Block were accomplished using TEAMS (Terrestrial Ecosystem Analysis and Modeling System), a decision support system developed by the School of Forestry, Northern Arizona University. TEAMS combines a geographic information system (GIS), a multiresource stand simulator, a linear programming optimization package, and a graphics output display program into an integrated information processing and retrieval system, all organized around a data base management system (Covington and others 1988). TEAMS allows for a relatively rapid analysis of various alternative management scenarios, with the goal of achieving an optimal solution to a given management problem. The version of TEAMS used in this analysis allows for planning and analysis over a forty year planning horizon.

The majority of the inventory data necessary for this analysis was provided by the Forest Service. For each stand, these data included stand boundaries, site index, and stand tables. A field inventory conducted by School of Forestry faculty and students generated the remaining data.

Inventory data were entered into the database, and all stand boundaries were digitized and entered through the GIS. Once the data were entered, the multiresource simulator was run to project the resource flows and stand conditions over time associated with a variety of silvicultural alternatives for each stand in the Block. Constraints were entered to mimic Forest Plan targets, standards, and guidelines. First, stand-specific constraints were written to prevent timber harvesting in

Table 1: Timber sale characteristics by sale area and total unit, Bar M 10-K block planning unit

Sale Area	Acres	Number of Stands	Stand Size (Ac) Min	Stand Size (Ac) Max	Site Index Min	Site Index Max
Bar M	4,627	108	3.5	177.4	47	90
Brolliar	2,624	58	2.0	285.0	53	89
Cracker	4,785	121	2.9	143.3	43	93
Long	2,589	77	2.8	242.0	52	90
Tie	1,276	37	2.6	150.0	53	89
BLOCK	15,901	401	2.6	285.0	43	93

Sale Area	Board Foot Volume per Acre: Min	Max	Ave	Standard Deviation	Coefficient of Variation
Bar M	0.0	32,034	7,639	5,011	65.6
Brolliar	0.0	22,150	10,232	6,577	64.3
Cracker	0.0	37,843	8,711	5,933	68.1
Long	0.0	20,462	8,903	5,725	64.3
Tie	0.0	17,594	8,329	4,878	58.6
BLOCK	0.0	37,843	8,644	5,698	65.9

all areas identified as having steep slopes. These areas were identified using the GIS capabilities of TEAMS. Although timber harvesting was prohibited, other resource values from these acres were included in the output.

Second, Forest Plan timber harvest targets were entered as constraints to the system. The total targeted timber harvest for the Bar M, Brolliar, Cracker, and Long sales, 36.3 MMBF, was added as the required sawtimber harvest during the first decade (Year 1) of the planning period. These targets were generated based on current stand volumes, aggregated first to the timber sale, and then to the entire Block. In addition, timber harvest constraints totalling 10 MMBF for Years 11 and 21 of the planning period were entered. These constraints were included to help insure long term availability of harvestable timber by requiring that timber volume is available for at least the second and third decades.

Third, Forest Plan standards and guidelines for acres of old growth and elk habitat were added. Initially, an old growth requirement was set at 5% of the Block (795 acres) beginning in Year 11. To force the provision of elk cover throughout the planning period, constraints were written to require that at least 30% of the Block be in conditions to provide elk cover throughout the planning period.

Once all constraints were entered, the linear programming optimization module was used to select from among the various silvicultural alternatives the set which would maximize the present net value of the Block while still meeting Forest Plan standards and guidelines.

Individual Timber Sale Analyses

The same basic procedures used for the 10-K Block analysis were followed for the analysis of each individual sale. Separate data bases were created from the overall Block data base to facilitate the analysis. The timber harvest targets shown in table 2 were entered for each sale. As noted above, these targets were generated based on current stand volumes, aggregated for each individual timber sale. The 10 MMBF maximum timber harvest levels in Years 11 and 21 were allocated to each sale proportional to its initial timber sale target. Slope constraints were added to each sale. Old growth targets were added to each sale to equal 5% of each sale area, beginning in Year 11. Elk cover constraints were added as for the entire 10-K Block.

In addition, the mean and variance of the volume per acre for each sale were compared to those of the Block as a whole to determine if there existed a statistically significant difference between these values, as a measure of relative homogeniety.

RESULTS

10-K Block Analysis

With all constraints in place, the initial run for the Bar M Block proved infeasible, due to the size of the old growth constraint for Year 11. A feasible solution was obtained only when the Year 11 constraint was reduced to 667 acres (4.2% of the Block), the maximum attainable old growth acres for that date. Old growth constraints were not binding in subsequent years.

Table 3 displays the outputs for the entire Block. Timber sale targets were met in each period, and except for Year 11 old growth, all other targets were achieved. Forage production during the analysis period ranged from a low of 727 Animal Unit Months (AUM's) in Year 41 to a high of 828 AUM's in Year 11. Incremental water yields ranged from a low of 238 acre feet above baseline flows in Year 21 to a high of 278 acre feet above baseline in Year 1, immediately following timber harvest activities. The present net value of this alternative, from timber harvesting, AUM's, and the value of the standing timber inventory, totaled $10,680,696, at a discount rate of 4%.

Table 2: Targeted timber harvest by timber sale, Bar M 10-K block

Sale Area	Timber Harvest (MBF)
Bar M	12,000
Brolliar	3,300
Cracker	11,000
Long	10,000
Tie	N/A
Total	36,300

Table 3: Resource output comparisons: Entire Bar M 10-K Block and the sum of timber sales within the 10-K Block

Resource Output	Total for 10-K Block	Total for Individual Sales
Present net worth ($)	10,680,696	10,617,862
Sawtimber harvest (MMBF)		
Year 1	36.3	36.3
Year 11	10.0	10.0
Year 21	10.0	10.0
Year 31	1.031	0.396
Old growth (acres)		
Year 1	560	532
Year 11	667	539
Year 21	1,562	1,137
Year 31	2,570	2,759
Year 41	2,629	2,877
Forage production (AUM's)		
Year 1	740	738
Year 11	828	833
Year 21	751	754
Year 31	35	738
Year 41	727	717
Incremental water yields (acre-feet)		
Year 1	278	278
Year 11	265	274
Year 21	238	241
Year 31	251	250
Year 41	265	246

Individual Timber Sale Analyses

Initial runs for three of the four individual timber sales, Bar M, Brolliar, and Cracker, proved infeasible due to the old growth constraint in Year 11. The maximum attainable old growth in Year 11 ranged from a low of 1.9% (92 acres) for the Cracker Sale to the full 5.0% (129 acres) for the Long Sale. Based on individual sale analyses, the maximum combined old growth achievable totaled 539 acres, 3.4% of the total area of the Bar M 10-K Block.

All other constraints were achieved for all sales, including providing a minimum of 5% of the Block in old growth after Year 11 of the analysis. The specified elk cover requirement was achieved in every period of the analysis. Sawtimber harvest levels were met for Years 1, 11, and 21. Combined forage production during the analysis

period ranged from a low of 717 AUM's in Year 41 to a high of 833 AUM's in Year 11. Combined incremental water yields ranged from a low of 241 acre feet above baseline flows in Year 21 to a high of 278 acre feet above baseline in Year 1, immediately following timber harvest activities (table 3). The total present net value of all five individual timber sales, again using a 4% discount rate, was $10,617,862.

The mean volume per acre for each sale was tested against the mean value for the entire Block, using the procedures for comparing a single mean to a specified value (Montgomery 1984). The variance in volume per acre for each individual sale was also compared to the overall Block variance using standard F-test procedures (Montgomery 1984). These results are shown in table 4. Only the mean volume per acre for the Bar M Sale was statistically different from the overall Block volume, at the 5% level. None of the variances of the individual sales were significantly different from the overall Block variance, again at the 5% level.

Table 4: Statistical Comparison of Individual Sale and Block Mean Volumes per Acre and Variances of Volume per Acre

	SALE CHARACTERISTIC			
	Test of Mean[1]		Test of Variance[4]	
Sale	Calculated[2]	Test[3]	Calculated[5]	Test[6]
Bar M	-2.084	2.00	0.773	1.32,.75
Brolliar	1.839	2.021	1.332	1.32,.75
Cracker	0.164	1.980	1.084	1.22,.82
Long	0.397	1.980	1.009	1.32,.75
Tie	-0.393	2.042	0.733	1.46,.68

NOTES:

[1] $H_0: u = u_0$
$H_1: u = u_0$
Where: u is the average volume per acre for each sale and u_0 is the overall average volume per acre for the Block.

[2] $t_0 = y^- - u_0/[s/n^{0.5}]$
Where: y^- = average volume per acre for each sale
u_0 = average volume per acre for Block
s = standard deviation of individual sale volume
n = number of stands in an individual sale

[3] $t_{a/2,\ n-1}$ Where: a = 0.05

[4] $H_0: o_1^2 = o_2^2$ Where: o_1^2 = variance in individual sale volume
$H_1: o_1^2 = o_2^2$ o_2^2 = variance in Block volume

[5] $F_0 = s_1^2/s_2^2$ Where: s_1^2 = variance in individual sale volume
s_2^2 = variance in Block volume

[6] $F_{a/2,\ n1-1,\ n2-1}$
$1/F_{a/2,\ n1-1,\ n2-1}$ Where: a = 0.05
n1 = degrees of freedom in numerator
n2 = degrees of freedom in denominator

DISCUSSION AND CONCLUSIONS

Little difference exists between the total outputs or the timing of resource flows generated in the total Block or individual sale analyses (table 3 and fig. 2 and 3). Although the present net value for the analysis of the entire Bar M Block was higher than the sum of the present net values for the individual sale alternatives, the difference was less than 1% of the total present net value for the Block. Sawtimber targets were achievable on either a sale-by-sale basis or as a collective target for the entire Block. Forage production and water yields did not appreciably differ between the analyses.

Only the old growth acres provided in Years 1 and 11 differed greatly between the analyses. More old growth acres could be generated on a Block-wide basis, while achieving timber harvest targets, than could be generated by the individual sale analysis. In Year 1, the Block-wide analysis provided 28 more acres of old growth than did the individual sale analysis, and in Year 11 the difference was 128 acres, a 23% increase over the that generated by the individual sale analysis. But in neither year could either analysis achieve the Forest Plan standard and guideline of 5% of the area, 795 acres, of old growth. The Block-wide analysis provided 3.5% and 4.2% of the Block acres in old growth conditions in Years 1 and 11, respectively. In Year 11, the 795 acre minimum old growth constraint cannot be achieved, regardless of Year 1 harvest levels. In Years 31 and 41, the old growth acres generated by the individual sales analysis exceeded that generated in the total Block analysis. This result is a function of harvesting in Year 31. Due to greater flexibility in selecting stands for harvest over time in the Block analysis, more timber is available and then harvested in Year 31 than in the individual sale analysis (table 3). As a result, fewer acres in the Block analysis qualify for old growth status in Years 31 and 41.

Although differences are not dramatic, these results are consistent with a commonly held hypothesis that applying Forest Plan standards and guidelines to large planning areas is less restrictive than applications to small areas. However, the relatively minor effects reported here are not really surprising given the questions

Old Growth Acres by Planning Unit

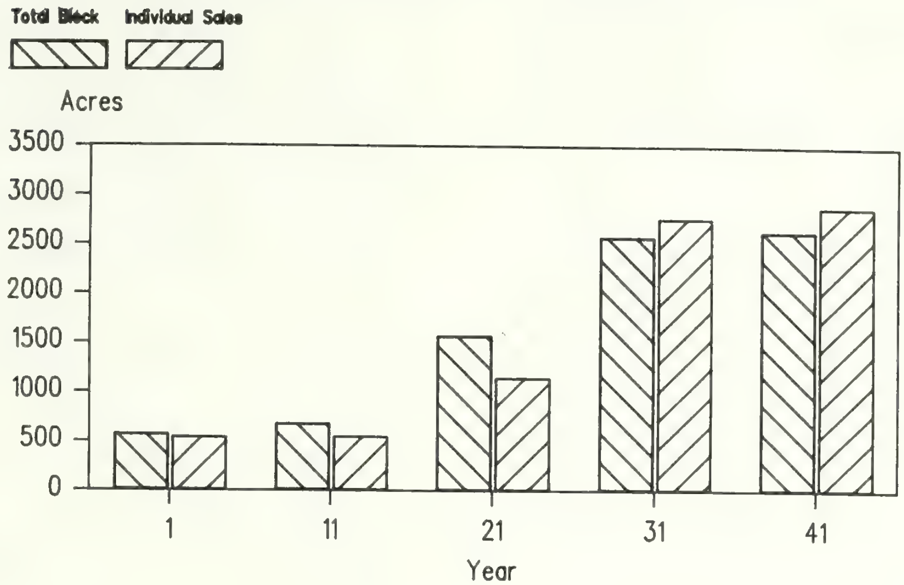

Figure 2: Old growth acres comparisons over time as a function of planning unit

Incremental Water Yield by Planning Unit

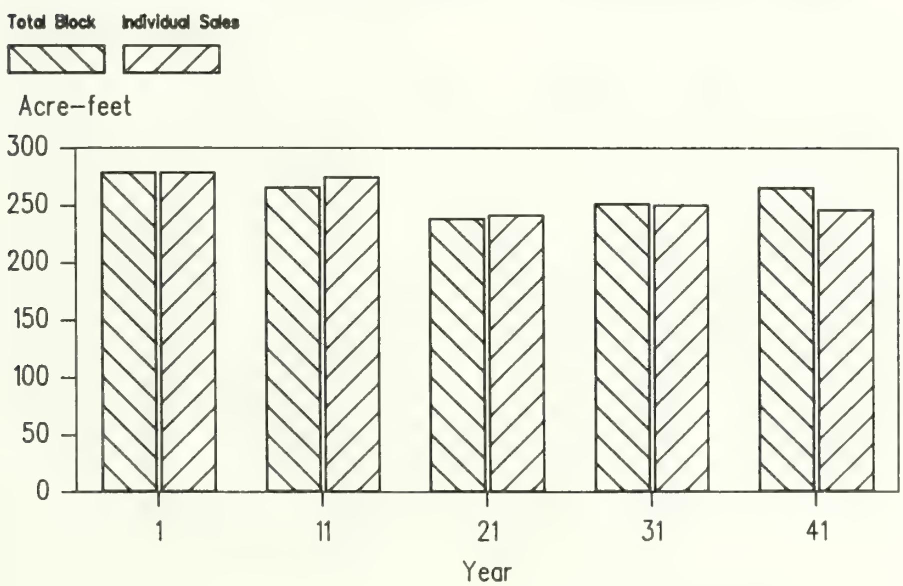

Figure 3: Incremental water yield comparisons over time as a function of planning unit

asked and the characteristics of the area studied, and they reflect three important and interrelated aspects of the planning process: the planning unit level used to generate targets, the basis for allocating resource targets, and the effect of the homogeneity of the area on the provision of a target resource.

The timber targets were generated based on current stand volumes, aggregated to the timber sale and 10-K Block levels. Therefore, little difficulty existed in obtaining the harvest volume targets either by individual sale or when allocated in aggregate to the entire Block, since the targets were built from below based on resource capabilities.

On the other hand, the provision of old growth acres did vary as a function of planning unit size. Old growth targets were generated based on Forest Plan standards and guidelines for all ponderosa pine areas on the forest with slopes less than 40%. This target was generated from above, and disaggregated to lower planning units. Thus as planning unit size decreases, from the forest, to the Block to the individual sale, old growth targets become increasingly difficult to meet.

The basis on which targets are allocated also influences the capability of a system to provide other resource outputs. Take, for example, the case of an individual timber sale, a unit of land defined primarily on the basis of providing one particular output, timber. Such an area will be unlikely to produce other resources in proportion to its ability to produce timber unless these other resources are highly and positively correlated to standing volume.

Last, as the homogeneity of the area analyzed increases, aggregating and disaggregating target resource outputs becomes easier. Only for the Bar M Sale is there a statistical difference between the mean volumes per acre for each timber sale and for the Bar M Block as a whole, and no statistical differences exist between the variances of the volume per acre for each individual sale and that for the overall Block variance (table 4). In terms of timber volumes, each sale represents a microcosm of the overall Block, and thus allocating timber targets to an individual sale was easy to achieve.

This analysis provides three lessons for those interested in forest planning. First, the ability of an area to provide resource outputs depends on the level from which targets are generated. If generated from below, the difficulties in achieving aggregate targets are minimized when these overall targets are subsequently disaggregated. For example, overall Forest-level timber harvest levels can be achieved if these harvest levels were built based on the aggregation of the capabilities of planning units that reflect actual resource capabilities. But for other resource targets not based on aggregation, such as old growth in this example, such disaggregation is not as easy because the targets do not reflect resource capabilities.

Second, the basis for allocating targets to particular units of land will impact resource outputs. Although volume may be, and probably is, an appropriate basis for allocating timber harvest, it is not necessarily the appropriate basis for allocating other resource targets, such as old growth acres or wildlife habitat.

Third, the more homogeneous an area with respect to a particular resource, the easier it is to disaggregate the output target for that resource. Under conditions where small planning units represent in microcosm the larger planning unit, the task of disaggregation to achieve desired output levels is greatly simplified. If, for example, every acre of a forest had identical timber characteristics, achieving harvest volume targets would be relatively easy indeed. But the complexity and difficulty of achieving output targets increases as management unit heterogeneity increases.

No easy answer exists for dealing with the problems identified above. However, the use of a DSS such as TEAMS allows for the rapid analysis of relatively large and complex allocation problems and can identify optimal solutions to these problems which satisfy management constraints. Such systems can be used to both generate potential resource outputs from below and to "best" allocate targets generated from above. As the Forest Plan implementation process continues, the number of such allocation problems will increase. Planning to achieve answers to these problems will require more sophistication than the Mylar map overlay and hard copy single-resource inventory data techniques that foresters

have used in the past. An alternative to such an approach would be

> "...A stand based data base interacting with the simulation model [that] could provide a quick evaluation of alternate spatial allocations using the most current stand conditions. If such a system is further integrated into an operating GIS, map work would be extensively reduced and intuitive problem solving would be facilitated" (Keller 1986, p. 129).

This is in essence the definition of a decision support system. Decision support systems such as TEAMS can greatly aid in the analysis of these complex planning problems to generate technically feasible solutions. Such solutions can then provide information useful for the essentially political task of deciding how "best" to manage the National Forests.

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Conflict Resolution in Multiresource Forest Management via Multiobjective Analysis[1]

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Abstract.--This paper develops and presents a methodology for conflict resolution in forest resources management. In the process, sources and possible types of conflicts are identified and some conflict analysis methods revised. Then, a ponderosa pine forest resources management problem with multiple conflicting objectives is solved using a cooperative game theoretical procedure. This leads to the determination of the most satisfying ponderosa pine forest treatment level under the conditions considered for analysis in this study. The treatment level which provides the vector of best objective function values is thinning the forest to a basal area of 48 to 60 ft^2/acre.

INTRODUCTION

Federal regulations and Forest Service guidelines require that national forests be managed for joint optimization of the different commodity resources (such as timber, herbage, water and minerals), amenity resources (such as wildlife, fish, visual quality and cultural values) and their supporting environment like soil, land and facilities. Even though all of these components are interrelated as parts of an interacting system, many of their interactions are competitive so that any management attempt for joint optimization, in the true meaning of the word, of all the resources in a forest system practically impossible.

Conflicts in forest resources management are further intensified by the presence of a variety of individuals and/or groups with conflicting interests and demands on the resources. This is particularly so in the ponderosa pine forests of the Southwest where there is not any particular dominant use, but rather the forest supports increasingly heavy demands by various user groups on both its commodity and amenity resources. Because of this situation, conflicts over forest resource use are common and seriously impact multiresource management. The conflict situation is further exacerbated by the lack of appropriate techniques for resolving such conflicts.

The nature of conflicts in forest resource management and the methods for dealing with the problem are discussed in this paper. First, the possible types of conflicts that can occur in the management of the resources in the southwestern ponderosa pine forest ecosystem are identified and described. Then, after a brief introductory review of the general conflict analysis procedure, a detailed description of the conflict resolution methodology used in this study is presented. This particular technique is the Nash-Harsanyi method (Goicoechea and others 1982) which uses a cooperative game theoretical concept to arrive at a compromise solution to a problem with several conflicting objectives. As an example of the latter, a ponderosa pine forest resource management problem with several objectives, some of which are

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conflicting, is formulated and solved. Once the problem is solved, the results are analyzed.

CONFLICTS IN FOREST RESOURCE MANAGEMENT

Forest resource management issues, concerns, and opportunities are characterized by a multiplicity of objectives, criteria, decision-makers, and constituents all impinging upon ecosystems. This makes the management of forest resources a complicated problem which requires decision making not only under several non-commensurable and conflicting objectives, but also in the presence of various groups of decision-makers and user constituents with conflicting interests in the different forest resource elements. Non-commensurability relates to the multiplicity of ways in which natural resources problems can be viewed or expressed simultaneously. Resources can be analyzed in terms of their economic benefits, aesthetic values, physical and biological components, and the social, cultural, political, and institutional conditions imposed upon their utilization.

Conflicts manifest of the existence of individuals or groups having different interests, goals, or objectives for a project, property or idea. Conflicts among interest groups or decision makers may be of varying intensity and complexity. Some may represent minor differences in the decision makers' points of view about an issue or ways of accomplishing a task, or they may strain the relationship among countries significantly (Fraser and Hipel 1984). Although conflicts may be as silent as citizen dissatisfaction about an issue, which is usually expressed indirectly through ballots or election returns, they may also be intense and even explosive. The latter type is usually manifested in court litigations, picket lines, street demonstrations, or even armed fighting.

Conflicts arise when a number of objectives cannot be optimized simultaneously. This occurs when the objectives are competitive, that is, when improvement in one objective is associated with deterioration in another. Psychologically, such a conflict is considered to occur when two or more motives are partially blocking each other (Zeleny 1982). According to this definition, the prime cause for conflict lies in the cognitive domain, in cognitive differences in perception or interpretation of the components of a given decision situation. As such, conflict becomes cognitive conflict generated by poor communication, misunderstanding, and positional inflexibility among parties. Socially and economically, conflict may also be defined as the interference by one or more individuals or groups on the attempt by others to achieve their social, and economic desires, or goals. These desires may be related to social equality, economic opportunity, or cultural, religious, or political freedom.

Conflicts in forest resources management may be caused by similar situations. Conflicting objectives in forest resources management may reflect different interests of a single decision-maker. A conflict of this nature, for example, may arise when a forest manager is confronted with the problem of attempting to maximize timber production while at the same time minimizing environmental degradation of the forest system. These two objectives are usually incompatible with each other and need some kind of tradeoff analysis. But in most cases, conflicting objectives represent conflicting desires of different decision makers or parties. Such conflicts are commonly encountered among parties because one party wants to get a larger share of some resource, such as timber, which comes at the expense of the other parties desiring the same resource. This kind of conflict is prevalent in the southwestern ponderosa pine forest areas among water users such as the Salt River Project on one hand and either Native American groups or other valley water users on the other. Such conflicts are also found among different timber companies who obtain their supply from the same forest areas.

There are also conflicts among groups who want different things from a forest system. Environmental groups and timber harvesters, for example, would like to see forests managed to satisfy their own specific desires. Another example of intergroup conflict in the area is between forest land developers, and traditional Native Americans who would like to maintain the sanctity of a particular area in the forest.

The forest resource management problem to be analyzed in this study is applicable to either conflict situations among different decision makers, or the single decision maker's dilemma when confronted with a number of conflicting objectives.

METHODS OF CONFLICT MANAGEMENT

Generally speaking, many conflict management schemes are known to have been used, some successfully and some not, to settle conflict situations that arise in the process of decision making. In this section a brief overview of conflict management methods is provided first, then followed by a detailed description of the particular technique used to evaluate the multiobjective problem under consideration.

An Overview of Conflict Management

People have tried many different ways of settling conflicts. Zeleny (1982) presents a repertoire of some common methods of conflict management including neglect, denial, containment, control, solution, resolution, and dissolution a brief discussion of which is provided herewith. Neglecting and denying a conflict situation are two different things. Neglecting a conflict means ignoring it or doing nothing about it, that is, letting it run its course without any interference. Denying implies refusing to accept the conflict's existence or reality such as by belittling major differences in decision making among different interest groups in forest resources management to make the situation look like a conflict-free environment. Such conflict denial usually involves the use of persuasion methods such as propaganda, brainwashing, or lying. In short, neither conflict neglect nor conflict denial lead to any positive steps in settling a dispute.

Conflict containment and control, on the other hand, can be helpful methods if applied properly. Conflict containment means temporarily freezing a conflict from progress to gain time for thinking and rationalization, while controlling a conflict involves allowing a conflict to progress within a certain limitation in accordance to prescribed rules. A conflict between wildlife managers and timber producers, for example, may be controlled by allowing loggers to cut trees as long as the cutting is done appropriately to leave adequate tree density for shelter in some areas, while cutting trees in others, to enhance forest browse production.

Conflict solution, resolution, and dissolution are more effective methods of settling conflicts. Solving a conflict is characterized by a single decision maker in a single objective environment or in an environment with multiple but complementary objectives, where optimizing the single objective or the complementary objectives is the sole criterion for action. Conflict resolution, on the other hand, involves consideration of multiple objectives some of which are in competition. It accepts the conditions which create the conflict, and seeks a compromise settlement, or consensus among the different decision makers involved. The process of resolving a conflict requires each party to give up something he or she originally desired in order to arrive at an equitable outcome or share for all parties concerned. Negotiation, mediation, arbitration, and bargaining are common tools used in conflict resolution. Conflict resolution, however, does not usually affect the conditions which produced the conflict situation, rather it results only in reducing the intensity of the conflict situation. Conflict elimination requires innovation, or inventing a new prominent alternative action that can result in a conflict-free situation. This is conflict dissolution. Since conflict dissolution is difficult to accomplish, however, most attempts of conflict management are usually geared toward resolving a conflict.

Mathematical techniques have been developed that can help resolve problems with conflicting objectives. Single objective problems can be handled using any classical optimization technique or mathematical programming procedures. To arrive at conflict resolution or dissolution, however, any one of a number of multiobjective programming techniques can be used (Zeleny 1982, Kok 1986). The techniques most commonly used in conflict analysis are usually based on the game theoretical concept. One such method is the so called conflict analysis of Fraser and Hipel (1984, 1989).

Conflict analysis is a reformulation and extension of metagame analysis (Howard 1971) which has some linkage with classical game theory (Von Neumann and Morgenstern 1953). The technique assumes no cooperation among participants when analyzing a problem with multiple conflicting objectives. This is in contrast to the cooperative game procedure being used to analyze the example problem in this paper. Another game theoretical procedure that can be applied to analyze conflicts in forest resource management is hypergame.

Hypergame is useful in a situation where one or more of the parties or participants have some misunderstanding about the true nature of the conflict situation (Fraser and Hipel 1984). This is usually the case when negotiating a sales contract. The buyer usually conceals the amount he or she is willing to pay in order to get the lowest possible deal. Information may also be hidden during negotiation by parties having conflicting interests in resource utilization with the intention of each side getting a better concession from the other.

Cooperative Game

In this paper, a cooperative game theoretical concept, known as the Nash cooperative game solution concept (1950, 1953) is employed as in Tecle and Duckstein (1989) to arrive at a compromise solution to the multiobjective ponderosa pine forest resources management problem under consideration. Game theory, in general, is a mathematical study of conflict resolution and may be classified as cooperative or non-cooperative game. In a cooperative game (CG), the participants have the opportunity to communicate with one another and form binding and enforceable agreements among themselves. Such an agreement results in the formulation of a payoff matrix as discussed in the next section.

A number of solution schemes have been proposed to J-person cooperative game problems (Rapoport 1970, Guiasu and others 1980). In most cases, the solution concepts are usually based on the subjective choice of weights, bounds and/or distances. The solution concept in this paper is, however, based on a certain set of axioms and the subjectivity of the decision maker (DM) in accepting or rejecting the axioms and determining the "status quo" point. The status quo point in a cooperative game is the vector of payoffs which all players can be sure of obtaining if they do not cooperate, and each tries to optimize his or her individual objectives. To state it quantitatively, let the payoff space be denoted by P and the elements in P by $f(j,k)$, for $j = 1, 2, \ldots, J$ and $k = 1, 2, \ldots, K$, then the status quo point is a disagreement vector, $\mathbf{f}^{**} \in P$ such that $\mathbf{f}^{**} = \{f_1^{**}, f_2^{**}, \ldots, f_J^{**}\}$, and also $f(j,k) \geq f_j^{**}$ in which $f(j,k) > f_j^{**}$ for at least one value of j (Rapoport, 1970).

Based on this assumption, Nash (1950, 1953) developed a solution procedure for two-player bargaining games. Harsanyi (1977) extended the Nash procedure to a J-players cooperative game ($J \geq 3$) to obtain a unique bargaining solution. The Nash-Harsanyi solution, $\mathbf{f}^*$ in which $\mathbf{f}^* = \{f_1^*, f_2^*, \ldots, f_J^*\}$ can be obtained using the following equation:

$$\mathbf{f}^* = \max[S_k = \prod_{j=1}^{J} (f(j,k) - f_j^{**})] \qquad (1)$$

subject to $f(j,k) \geq f_j^{**}$, and $f(j,k) \in P$; and $\mathbf{f}^{**}$ is as described above, while S_k is a vector valued achievement level of the objectives under a particular k ($k = 1, 2, \ldots, K$) treatment level.

This equation can be derived in one of two ways. It can be obtained using Zeuthen's bargaining principle (Zeuthen 1930) which states that the next concession always comes from the objective having the least risk in a conflict. It can also be derived from satisfying Nash's axioms which can be described as follows:

1. Feasibility. The payoff space, P, of the cooperative game is always closed, bounded, and convex, and that there exists at least one $f(j,k) \in P$ such that $f(j,k) > f_j^{**}$ as stated above.

2. Collective rationality. If $\mathbf{f}^* = (f_1^*, f_2^*, \ldots, f_J^*)$ is a solution, there is not any other point in the payoff space, P, which yields every player a payoff higher than $\mathbf{f}^*$.

3. Joint efficiency. Players joining in a coalition can get jointly more than the sum of what they can get if they play every man for himself against a coalition of all others. That is, the efficiency is synergistic. If $\mathbf{f}^*$ is nondominated in P, there is not any other vector $\mathbf{h} \in P$, $\mathbf{h} \neq \mathbf{f}^*$ such that $\mathbf{h} \geq \mathbf{f}^*$.

4. Symmetry. If the game is symmetric, every player gets the same payoff.

5. Linear invariance. If two versions of the same bargaining game differ only in the units and origins of the utility function, then the respective solutions are related by the same utility transformation.

6. Independence of irrelevant alternatives. If the payoff space of the multiobjective problem is expanded, while the status quo

point remains the same, then the new solution must either be in the added space or remain in the original space. Likewise, if a payoff space which does not contain the solution is deleted while the status quo point remains the same, then the solution would also remain the same.

The idea is that if the players agree to accept the axioms as general principles then they can apply a bargaining procedure that satisfies the axioms in all situations in order to get a satisfying solution. This procedure and Zeuthen's bargaining procedure arrive at the same solution (Harsanyi 1977) which can be obtained using the above Nash-Harsanyi model (Szidarovszky and others 1984). In this study, the Nash cooperative game procedure is used to analyze a forest resource management problem with conflicting objectives.

FOREST RESOURCES MANAGEMENT CASE EXAMPLE

To illustrate the application of conflict analysis to multiresource management, a simplified problem using data from the ponderosa pine forests of the Beaver Creek Watershed is analyzed. The Beaver Creek Watershed is located about 30 miles south of Flagstaff, Arizona, in the Coconino National Forest. This watershed was used as a study area for a 22 year experimental pilot project to demonstrate multipurpose forest resource management. During that period different parts of the watershed were subjected to varying vegetation treatment levels to determine the effects of such treatments on the forest resources and conditions in the area. Descriptions of the different vegetation treatments performed can be found in USDA Forest Service (1977), Brown and others (1974), Ffolliott and Thorud (1975), Baker (1982, 1986) and Tecle and others (1988). Data on the effect of treatment levels on water runoff, sediment yield, flood magnitude, wildlife, range forage, recreational use, and scenic beauty have been collected, and analyzed to produce resource response functions showing how vegetation modification practices affect these outputs (Brown 1976, Baker and Rogers 1983, Hibbert 1983, Mitchell and Joyce 1986).

In this paper, a systems approach to a complex resources management problem in which compromises are made among conflicting objectives is described. The complexity of multiresource management stems from the interaction of a hierarchy of complex and dynamic systems including a landscape of ecological systems and national, regional, and local social and political systems.

A conceptual framework for analyzing multiresource management problems can be derived from a set model proposed by Rolfe Leary (1985) in his 1985 book, Interaction Theory in Forest Ecology and Management. Taking a few liberties with Leary's set model, multiresource management can be viewed as the interaction of sets of resources (both biotic and abiotic), users (both human and other biotic users), specific locations, time, natural disturbances, and management. Symbolically this can be expressed as:

$$MRM = R_a \times R_b \times U_b \times U_h \times L \times T \times D \times M \times SP \qquad (2)$$

where:
MRM = multiresource management
R_a = abiotic resources (water, soil, nutrients, salt licks, etc.)
R_b = biotic resources (trees, shrubs, grasses, forbs, animals, microbes, etc.)
U_b = biotic users of populations (all biota except humans)
U_h = human users of populations (as biota with technology for extensive impacts)
L = geographic locations (stands, management units, watersheds, districts, national forests, states, etc.)
T = time (time steps from hourly through centuries)
D = disturbances (fire, drought, insect outbreak, etc.)
M = management activities (burning, fencing, thinning, harvesting, fertilization, road building, recreation site development, etc.)
SP = sociopolitical factors (local, regional, and national)

This model leads those concerned with multiresource management to think more clearly and more comprehensively when analyzing alternative management strategies.

To illustrate this approach we consider a multiresource management analysis where parties are concerned with the abiotic resource of water, the biotic resource of herbage, the biotic resource of deer, the biotic resource of livestock, the human users of water, the human users of recreation, the human users of timber, a single location, a time span of 5-10 years since the initial treatment, the management activities of harvesting and thinning,

and the overall treatment cost. In this paper, the procedure was demonstrated by analyzing data gathered from different parts of a particular forest watershed, the Beaver Creek Watershed. And even though the data was obtained from a number of subwatersheds each subjected to a different vegetation treatment level, the subwatersheds were considered spatially homogenous to simplify the problem for analysis. Further simplication was also made by not including other disturbances, sociopolitical factors, and information from locations outside the study site.

To analyze the problem, five general objectives, eight resource criteria (table 1), and eight response functions (fig. 1), one for each criterion were developed (Tecle 1988) in accordance with USDA Forest Service's multipurpose forest resources management guidelines (USDA Forest Service 1982). The response functions are constructed for joint analysis in a multiobjective framework (Tecle 1987, Tecle and others 1988). The desire is to enable obtaining the best possible combination of outputs from the forest system while at the same time accounting for environmental impacts of the particular management activity, and also resolving conflicts among different interest groups having a stake in the way the resources are managed.

The eight resource response functions have been used as objective functions to express the interests and aspirations of different forest resources managers and other interest groups. The objectives are:

(1) Maximizing water yield
(2) Minimizing sediment loss
(3) Minimizing flood magnitude
(4) Improving deer habitat
(5) Maximizing aesthetic values
(6) Maximizing forage production
(7) Maximizing timber production, and
(8) Minimizing total cost

For simplicity, a regression analysis of the data was conducted leading to eight polynomial functions described in the following general form. The equation is a function of a single independent variable, percent basal area removed.

$$f_j(x) = \sum_i a_i x^i, \quad j = 1, 2, \ldots, J \qquad (3)$$

where

$f_j(x)$ = value of objective function j, (j = 1, ..., J)
J = the number of objective functions, which is 8

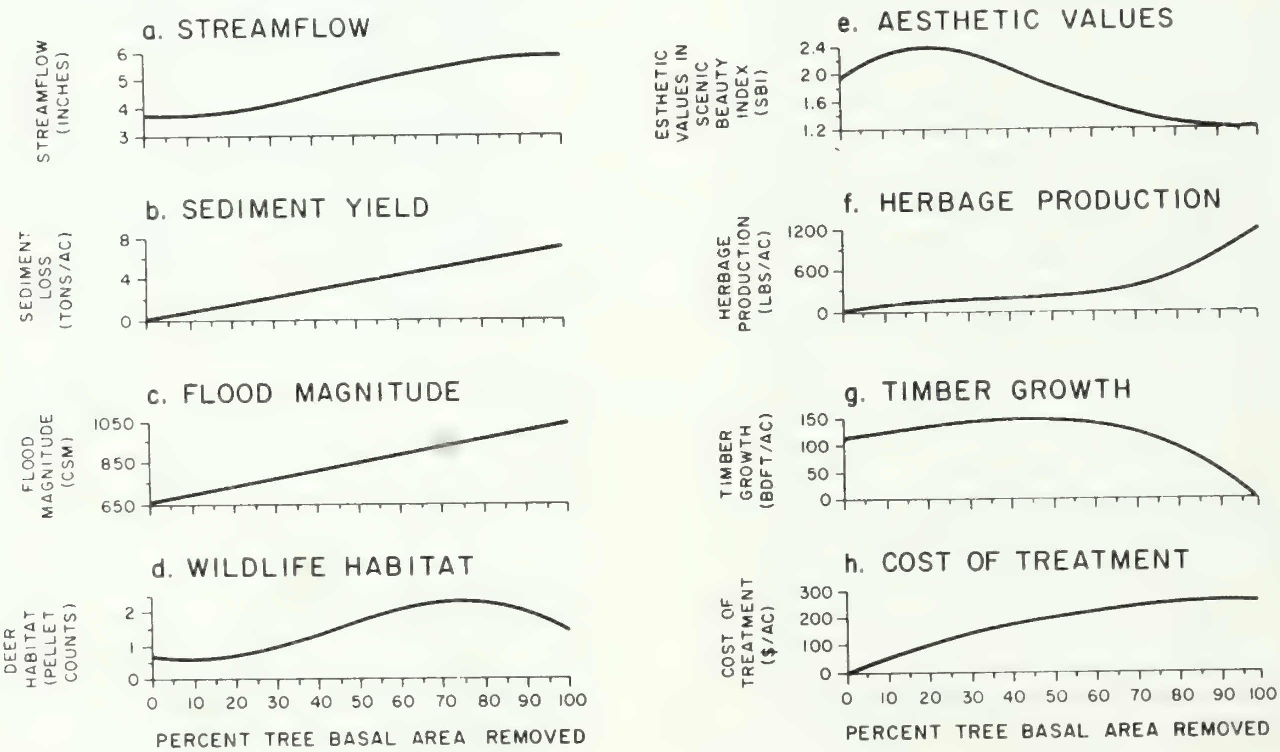

Figure 1. Effect of vegetation management on different forest resources.

$i = 0,1,2, \ldots$ is the exponent of x
a_i = coefficient of x^i, and
x = percent basal area removed from the ponderosa pine forest in the Beaver Creek Watershed.

Determination of percent basal area removal is based on an average tree basal area of 120 ft^2 per acre for untreated ponderosa pine forest on Siesta-Sponseller soils in the Beaver Creek Watershed as reported in, for example, Brown and others (1974), Baker (1975) and Brown (1981). Under this condition, a watershed having 50% of its tree basal area removed is considered to be equivalent to one having 60 ft^2/acre tree basal area. Tree basal area is the area in square feet occupied by living trees on one acre of land (Forbes and Meyer 1961, Brown 1981). Basal area is determined by measuring the cross section of the trunk of sample trees at a point 4.5 feet above ground. Since the trees in the watersheds are not distributed uniformly, the average basal area on the study site was used to construct the resource response functions. These functions are presented graphically in Figure 1. The individual graphs in the figure are the response function curves for the 8 different resource elements under consideration.

Information for developing the resources response functions was obtained from previously collected data on the Beaver Creek experimental watershed. The annual averages for a five-year data set for different vegetation treatment levels have been used in combination with supplemental information from various published materials such as those in Brown and others (1974), Baker and Brown (1974), Ffolliott and Thorud (1974, 1975), Baker (1982, 1986), Brown (1982), and Ffolliott and others (1989).

APPLICATION AND ANALYSIS OF RESULTS

In order to apply the Nash solution concept of cooperative game approach to the multiobjective forest resource management problem, discrete values of the eight objective functions for each one of 15 vegetation treatment levels were obtained. The 15 treatment levels consisting of A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11, A12, A13, A14, and A15, respectively represent 0, 15, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 85, and 100 per cent tree basal area removal. These are assumed to be feasible alternatives from which the most satisfying treatment level can be selected. The values of the resource

Table 1. Objectives, specifications, criteria and criterion measures of the ponderosa pine forest resources management problem.

Objectives	Specifications	Criteria	criterion measures
Increase water yield	water quantity, streamflow,	streamflow	Net change (inches)
	water quality, sediment yield,	sediment yield	Tons per acre
	flood hazard	flood level	cubic feet/sec/mi^2
Develop recreation	recreation use (camping, hiking, hunting, fishing, horse riding,	deer population density	pellet group count
	nongame use, sight seeing, picnicking, fauna-flora structure and others)	aesthetic value	scenic beauty index
Improve range condition	livestock and wildlife forage	herbage production	pounds per acre
Timber production	timber stand improvement (both quality saw timber, and quantity), fire wood and fence post	timber growth	board feet per acre
Minimize total cost	O and M cost* capital and indirect cost	total cost	dollars per acre

*O = operation, and M = maintenance

response functions in figure 1 corresponding to these treatment levels were obtained and constructed to form the evaluation matrix of table 2. Then the Nash-Harsanyi solution procedure specified in the previous section is utilized to select the compromise treatment level.

In applying the Nash-Harsanyi model to the evaluation matrix of table 2, the geometric distances from the status quo point of the 15 points, each point representing a vector of criterion function values, S_k under alternative treatment level k (k = 1, 2, ..., 15) were determined. This was done, by first choosing from f(j,k), the minimum value for each criterion j as the status quo point. The criterion values in column 2 of table 4 constitute the status quo point for the problem considered. Then using equation [1], the geometric distance of point S_6 (which is the compromise point) was determined as follows:

$$[(4.49-3.68)*(-3.2+7.56)*(-818+1040.1)*(2.1-1.15)*(1.41-0.53)*(204-0.66)*(147.5-0.32)*(-168+259.1)] = 0.1788E+10 \qquad (4)$$

Such computation was made 15 times, one for each alternative treatment level. And maximizing the 15 distances provides the unique compromise solution, S_6. Thus, alternative A6 representing 40% (48 ft^2/acre) basal area cut, with a residual basal area of 72 ft^2/acre is found to be the compromise solution to the problem under consideration. Figuratively, this solution represents a saddle point (in a 2-dimensional sense) in the feasible payoff space.

To demonstrate the solution procedure in a 2-dimensional graph, the wildlife habitat (in deer pellet counts) and aesthetics (in scenic beauty index) response functions are drawn in figure 2. The individual optimum values of these response functions are 2.38 (in scenic beauty index) at 20% cut for aesthetics, and 2.38 (in pellet counts) at 75% cut for deer. These values which are shown, respectively, as points **a** and

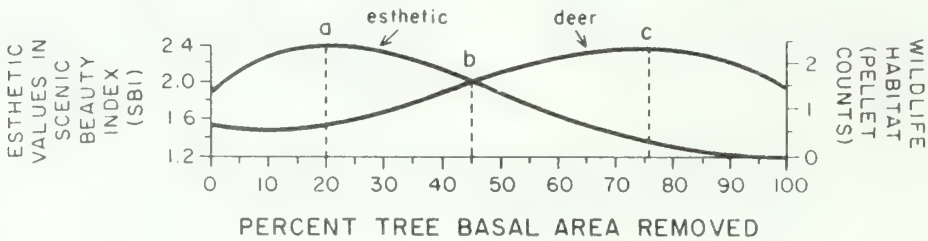

Figure 2. Graphical representation of a compromise solution for a problem with two competitive objectives.

Table 2. Evaluation matrix: criterion function values versus alternatives

	Alternative treatments as percent tree basal area cut														
Criteria	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
Streamflow (inches)	3.78	3.85	4.05	4.18	4.33	4.49	4.66	4.84	5.02	5.19	5.36	5.51	5.65	5.86	5 95
Sed. yield (tons/ac)	-0.12	-1.36	-2.12	-2.49	-2.85	-3.20	-3.55	-3.89	-4.24	-4.58	-4.92	-5.26	-5.61	-6.32	-7.46
Flood lev. (CSM)	-655.	-717.	-758.	-778.	-798.	-818.	-838.	-858.	-877.	-897.	-916.	-934.	-953.	-989.	-1040.
Aesthetic (index)	1.91	2.36	2.36	2.30	2.21	2.10	1.99	1.86	1.74	1.63	1.52	1.43	1.36	1.26	1.25
deer pellet (counts)	0.67	0.63	0.86	1.03	1.21	1.41	1.61	1.81	1.99	2.15	2.27	2.35	2.38	2.24	1.43
Herbage production (lbs/ac)	0.76	128.	168.	183.	194.	204.	213.	223.	237.	259.	291.	337.	401.	606.	1185.
Timber growth (bdft/ac)	116.	130.	139.	143.	146.	147.5	148.	147.	144.	140.	133.	123.	111.	77.	.42
Total cost ($/acre)	-4.71	-76.6	-117.	-135.	-152.	-168.	-182.	-196.	-208.	-219.	-229.	-237.	-245.	-255.	-259.

c in figure 2, cannot be achieved simultaneously. They are competitive. Thus, the compromise treatment level which would yield the best value for each objective such that any improvement in either objective values would be impossible without adversely affecting the other is 45% basal area cut. This cut would give the compromise solution at point **b** (fig. 2) with the values of 1.61 for wildlife and 1.99 for aesthetics. Furthermore, if in addition to specifying the status quo point, other constraints are also introduced to represent a maximum acceptability of foregone benefits or costs, then the solution would be different. For example, if it were determined that the threshold value for wildlife survival was a minimum value of 2 deer pellet counts, then the preferred treatment would be 55% cut which would yield a compromise solution of 2 for wildlife, and about 1.7 for aesthetics (fig. 2).

Using the computed geometric distances as criteria, a preference ranking of the different alternative treatment schemes was made as shown in table 3. In order of preference, A6, 40% tree basal area removal followed by A7, the alternative with 45% removal are the best alternative management schemes for the problem under consideration. The worst is A15, the 100% tree basal area removal alternative. The other treatment levels occupy intermediate rankings as shown in table 3. The values of the criterion functions corresponding to each alternative vegetation treatment level are found in table 2 under the columns representing each specific treatment level.

The vector of criterion function values for the selected alternative vegetation treatment level, A6, is compared to other vectors of criterion function values in table 4. Specifically, the criterion function values for the first choice alternative action, A6 (Column 3), the second choice, A7 (column 4), the worst criterion values, or status quo point (column 2), and the best possible criterion values that can be obtained for each function if each were optimized separately (column 5) are compared. This comparison clearly shows where the criterion function values under the preferred alternative treatment level lie in comparison with the highest and lowest criterion function values. Aesthetic value is close to the optimal value; however, others, such as sediment yield, flood level, and wildlife conditions, lie midway between the two extremes, while streamflow, herbage production and total cost are closer to the minimum values. The level of timber yield is optimized under the selected compromise alternative management level, A6, the 40% tree basal area removal.

Table 3. Ranking of alternative treatment schemes

Alternative scheme (1)	Relative distance (2)	Ranking (3)
A1	.8971E+05	14
A2	.1242E+09	11
A3	.7477E+09	7
A4	.1233E+10	5
A5	.1612E+10	3
A6	.1788E+10	1
A7	.1742E+10	2
A8	.1450E+10	4
A9	.1085E+10	6
A10	.7245E+09	8
A11	.4109E+09	9
A12	.2075E+09	10
A13	.8121E+08	12
A14	.4945E+07	13
A15	.2419E-01	15

CONCLUSIONS

Conflicts can provide decision makers with a decision motivating tension, and a frustration and dissatisfaction with the status quo, as well as a desire for resolving the conflict situation. In this study, modeling possible conflicts among different forest resources managers and interest groups lead, first, to the formulation of a resources management problem with eight conflicting objectives. The objectives are considered to represent the interests and aspirations of the different resources managers and other interest groups. Then, a mathematical bargaining procedure which assumes existence of cooperation among the participants is used to analyze the problem. This procedure is the Nash-Harsanyi cooperative game procedure which results in a compromise solution.

In conclusion, cooperative game theoretical concept can be successfully used to arrive at a compromise solution to a multiresource management problem with non-commensurate, and conflicting

Table 4. Comparing criterion function values for the selected alternative treatment level with the vectors of worst and best criterion function values.

Criterion function (1)	Worst value (2)	value for 1st Choice (3)	value for 2nd choice (4)	Best values (5)
Streamflow (inches)	3.78	4.49	4.66	5.95
Sediment yield (tons/acre)	-7.56	-3.20	-3.55	-0.12
Flood level (CSM)	-1040.00	-818.00	-838.00	-655.00
Aesthetic index (index)	1.25	2.10	1.99	2.36
Deer pellet (counts)	0.63	1.41	1.61	2.38
Herbage production (lbs/acre)	0.76	204.00	213.00	1185.00
Timber growth (bdft/acre)	0.42	**147.50**	**148.00**	**148.00**
Total cost ($/acre)	-259.00	-168.00	-182.00	-4.71

objectives. The requirement is that certain axioms which the solution must satisfy, such as Nash's axioms have to be accepted a priori. . Once the parties accept the axioms (or Zeunthen's bargaining principle), and choose the "status quo" point, the technique enables determination of a unique solution to the multiobjective forest resource management problem. The status quo point may be either the Nash equilibrium point, a minimum solution point (Harsanyi 1977), or the result of the subjective choice of the decision maker. In this paper, the status quo point is taken to be the Nash equilibrium point minus 0.1 to avoid multiplication by zero. The process results in selecting alternative A6, the vegetation treatment level with 40% tree basal area removed. However, as is true in all problem solving techniques, the simplifying assumptions considered, the analytical techniques employed, and the adequacy of data gathered determine the outcome. Different assumptions, extensive data base on resource mixes, resource response functions, and use of other techniques may result in a different compromise solution.

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Insect Pest Management Expert Systems in Multiresource Management of Ponderosa Pine[1]

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Abstract.--Expert systems have received considerable attention in entomology research in the last few years. Some researchers look to this information technology with high hopes of improved computer based decision making. To others it is a new gimmick; a new toy for computer buffs. An overview of the concept of expert systems and how this technology can be useful to foresters is explored in this paper. Existing entomology expert systems are reviewed and possibility of integrating expert systems into the pest management decision process is discussed.

INTRODUCTION

Decision making in forest pest management is a complex procedure involving insect population models, theories, hunches, and voluminous biological information. Managers must evaluate problems of pest activity, estimate future effects of the insects and potential problems, develop possible management plans, consider the effect the plan will have on other resources, and select a final course of action. The effectiveness of all this activity is a function of how well the manager can obtain and make use of existing knowledge (Rykiel et al. 1984, Power 1988). Recent advances in modeling and simulating together with stepped up research have increased the quality and quantity of information available to the manager but access to the information remains difficult and interpreting it even harder (Rykiel et al. 1984).

In response to this problem, congress passed 3 laws in 1978 authorizing technology transfer by states, extension branches of land grant colleges and universities, and the USDA Forest Service. Shortly after this, the Forest Service expanded its Office of Technology Transfer to improve coordination with others and to strengthen its efforts (Muth and Hendee 1980). But the rate of knowledge acquisition is rising so fast that managers cannot keep up with the new information. Colleges and universities are asked to find ways to rapidly and effectively deliver this information to the managers.

The most promising means of information transfer is through computer technology. Computers have been accepted by the general public with remarkably little controversy (Mazur 1987) and it looks like computer use will increase in the future (Stone et all. 1986). Rauscher (1987) emphasized this point through a comparison with the industrial revolution: "The first industrial revolution was characterized by machines that enhanced our physical capacity to work, while the second industrial revolution (in process) is based on machines that enhance our mental capacity to do work".

Early computers were used for structured problems with fixed purposes. Computer systems were used in entomology to process data and information with programs such as file management, data base management, simulation models and management information systems (Coulson and Saunders 1987). But systems are needed which can deal with unstructured problem

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solving. We need systems that not only provide access to the information but can integrate the information for use, interpret the information and can serve as a coach to guide the user in problem solving (Coulson and Saunders 1987). Work is in progress to develop software systems that mimic the deductive and inductive reasoning of a human expert. The systems are called Expert Systems.

In this paper we will describe what Expert Systems are, how they are made, and what use they can be in forest entomology decision making. We will review Expert Systems that have been developed for insect pest management and summarize what has been learned from this work. We will also discuss how Expert Systems fit in with the general scheme of decision making and suggest future needs for an efficient information transfer system.

Background of Expert System Development

Since the time computers were invented researchers have dreamed of making an intelligent system for problem solving. The term Artificial Intelligence (AI) was first used in 1956 by John McCarthy at Dartmouth College. One of the first AI programs was written in 1957 by Allen Newell and Herbert Simon of Carnegie-Mellon University and J. Clifford Shaw of the RAND Corporation. It was called General Problem Solver (Waldrop 1984). The idea was to mimic human problem solving techniques with the computer. But it failed miserably because of the combinatoric explosion from all the millions of possible combinations in the solution process. Even a simple game like checkers has 10^{40} possible sequences (Waldrop 1984).

In an attempt to mimic the human brain, early researchers experimented with program structures called neural nets (imitating the neurons of a human brain) (Forsythe 1984). The researchers were surprised at how big a problem they came up against. The hardware was nowhere near capable of imitating the 10 billion neurons of a human. So AI researchers started using "heuristics" or rules of thumb to reduce the number of possible choices. Specialized knowledge was needed to form the rules, and as research progressed, more and more knowledge was needed until in the mid 1970s the idea of intelligence had changed. The concept of ability to reason had given way to the concept of having lots of specific knowledge about lots of subjects as the most important aspect of intelligence (Waldrop 1984).

Researchers questioned if reasoning ability was really all that important to intelligence. An expert seemed to just look at a problem as a whole and see a solution. It was less a matter of reasoning than of recognition of patterns in a large memory store house of knowledge and experience. Experts seemed to use reasoning only on unfamiliar problems. Thus knowledge programming came into the forefront of AI. The purest and most narrowly defined form of knowledge programming is Expert Systems (ExS) (Waldrop 1984).

Expert Systems

Definition

The definition we will use for ExS in this paper was given by Stone et al.(1986): "Expert Systems are computer programs that offer solutions to complex problems by mimicking human reasoning process (heuristics) and employing knowledge base of information extracted from human experts." ExS are different from conventional programs in that they maintain a clear separation between the knowledge base and the mechanism for applying that knowledge to a specific problem (Rauscher 1987). In conventional programs knowledge items are mixed in with the program control statements for the solution of one specific problem. ExS, however, have a knowledge base separate from the control program (inference engine). When a problem is put before the computer, the inference engine looks at the knowledge base for answers to questions needed to solve the problem. These systems are much more versatile than conventional programs since they have the ability to use the same knowledge base to solve more than one specific problems.

Advantages

Coulson and Saunders (1987) list several advantages of ExS over conventional programs. First, both objective (simulation models and technical information) and subjective (expert opinions) information can be maintained in the knowledge base. Second, since the inference engine that runs the ExS uses pattern matching instead of the standard encoded branching method, it is nonprocedural and more flexible. It can handle a wider range of questions. Third, the control program and knowledge base are separate which simplifies maintenance and updating of the ExS. Fourth, ExS can deal with imprecise and incomplete information. Fifth, ExS can explain the steps taken in problem solving to the user since it "remembers" the chain of reasoning used. Sixth, a user need not have any special expertise to use the system.

ExS Basics

The idea of ExS is not really profound. Basically, ExS tie together if/then statements to produce reasonable inferences. They work well if: 1. The problem is well bounded, 2. There are many empirical if/thens that lead to a correct solution, 3. The total number of if/thens is sufficient to bring you close to a right answer (Mazur 1987).

ExS can be divided into two types: Diagnosis ExS and Decision-aid ExS (Stone et al. 1986). Many pest management problems can be solved with ExS of the first type. Insect identification and finding the best insecticide to use are two examples. These systems often are easy to build and can in cases be little more than a glorified dichotomous key. Decision-aid ExS, however, are more complex and usually interact with a model or simulation program and interpret the results.

Why Bother With Expert Systems?

Expert Systems have been promoted by excited researchers as "potentially the biggest thing since the industrial revolution" (Cohen 1987), "one of the fastest growing computer technologies in the world today" (Stock 1988); and they "perform at the level of human experts" (Lemmon 1986). ExS are even placed in the category of "artificial intelligence" in the computer programming field. But perhaps it is a little too over played. As Mazur (1987) said in his address to the Forest Resources Symposium, "AI is overblown by 'hype', by exaggerated self advertisement". Machines cannot match the intui-tive intelligence that human beings have (Dreyfus and Dreyfus 1986). Some ExS that have been developed are in reality quite simple. Many diagnosis type ExS can be accomplished by a simple look up table (Cohen 1987). One might wonder if it is a little overkill to use an expensive computer to do something a sheet of paper can do.

On the positive side, however, ExS can bridge the gap between researchers and field use by managers. Researchers are experts at developing models and using them in problem analysis. They develop complex models to understand concepts like dynamics of insect populations but have little time to teach the use of these models to personnel in the field. When a problem comes up, the manager must find how the simulation model can solve it or at least provide some aid in understanding the problem. This is where ExS can contribute greatly to the decision making process. They can keep the knowledge base and simulation programs hidden to the decision maker so he can get the information he wants and focus on the problem at hand without having to see the complex routines used to come up with the answer. The ExS can then interpret the result of the simulation models so non-expert managers can understand. Cohen (1987) put it another way: "ExS may be most useful in advising non-experts in that part of the domain of interest regarded by human experts as routine". If more depth of understanding is desired, the manager can then question the ExS how it comes up with its solution and why. A manager can be deeply involved with the decision process or allow the computer to do it all and just accept the output of the program.

ExS can encourage users to actively participate in the knowledge acquisition necessary to solve the problem. In a follow-up study of the potato leaf hopper ExS, PLEX, developed at Pennsylvania State University the ExS stimulated farmers to gather necessary extra data when using the system because the value of this information was made clear by the ExS (Rajotte et al. 1988).Rauscher (1987) discussed six ways ExS can help improve productivity: 1. Capturing, refining, packaging and distributing expertise, 2. Solving problems that exceed the ability of non-experts, 3. Solving problems where the required scope of knowledge exceeds any individuals, 4. Creating an organization memory, 5. Avoiding delays when crises occur, and 6. Conserving the time of human experts. Most experts are scarce and in high demand. They are a valuable source of information but their knowledge is perishable. Experts get sick, die, change jobs, and often simply have "bad days". ExS can record their valuable knowledge for a permanent record easily accessible and consistent from day to day. And small scale ExS can take over some of the more routine aspects of an expert's job (Stock 1987).

Development of an Expert System

A good summary of points to check when planning ExS is given by Stock (1988). Actual development consists of five stages: Problem identification, working with an expert to develop the basic concepts, formalizing these concepts into a form that can be used by the program, writing the computer code, and testing (Waterman 1986).

Problem identification is a critical step in developing ExS. The problem should be well defined, a manageable size, and require a human expert to solve. "Problems that involve incomplete data and require judgement, approximation, or opinion in their solution are not well suited to an Expert System's approach" (Stone et al. 1986). Stock (1987) listed several criteria for judging the suitability of a problem for ExS. Most successful systems fulfill many of the following criteria: 1. The expertise should be scarce and not easily passed to novices, 2. The problem domain should be narrow but highly specialized, and there should be a larger number of possible solutions to the problem than can be realistically and thoroughly considered by a human trying to solve the task, 3. The problem solution should require heuristics (logic rules instead of just a set of equations), 4. The scope of the problem must be constrained for initial work, 5. Experts must exist who can competently solve the problem, and one of these experts must be able and willing to co-operate with the development of the ExS, 6. There should be a clear financial justification for building the system, 7. Experts in the area should agree - controversial subjects are

not appropriate for ExS, and 8. Ample data, test cases, and potential users should be available for validity testing and acceptability testing of the system.

In the conceptualization stage the system developer and expert decide what concepts, relations, and problem solving strategies are necessary for the problems covered by the ExS. Decisions are also made concerning the level of detail needed for the knowledge base and if any problem solving constraints are necessary. At this stage, the system developer conducts an extensive literature review and interviews one or more experts to gather the knowledge, theories, and problem solving techniques and rules of thumb used for solving the problems covered by the ExS.

The formalization step involves the expression of the concepts and relations in a formal way that will allow them to be used within the framework of the ExS program. The knowledge gathered in the previous step must be translated from pages of notes, thoughts, and ideas to some format usable by the computer.

Implementation is the step of actually creating the ExS computer program. ExS contains a user interface, a knowledge base, and an inference engine (Stock 1987). The user interface is the part of the program that interacts with the user, usually in a natural language (ie. English). The knowledge base is a data base of appropriate facts and rules (heuristics). The rules are usually rules of good judgement used by the expert in problem analysis. Typically, rules follow a form similar to: If (fact) Then (conclusion). For example, <u>If</u> the tree has tiny holes in the bark <u>Then</u> look for bark beetle larvae. The inference engine controls the reasoning process and interacts with the user interface and knowledge base to maintain the flow of the program.

Finally, the system is tested for accuracy and usability. Several phases of testing should be included at various levels. Rajotte et al. (1988) list a few as follows. The developers must check the system for system errors and the knowledge base to make sure it is accurate. A set of problems with known solutions should be set before the system and human experts to compare the solutions obtained. Next, the system should be checked by colleagues who are experts in the same field as the ExS. Then a pilot study should be arranged using a sample of the potential users to make sure it is appropriate to their needs. Finally the software is prepared for general use after all errors and problems are corrected. But even after release, the system must be monitored to obtain suggestions for improvement and update the knowledge base as new information is produced by researchers.

Application to Forestry

ExS can benefit forestry in three main ways: as decision making aids, forest science librarian, and in forestry education (Rauscher 1987).

The forest manager can use ExS in place of or in addition to a staff of specialists. When experts are rare and in high demand, ExS can relieve a lot of pressure on both the experts and managers. The final decision must be made by the manager who evaluates the results of the ExS and recommendations made by his staff.

Getting the right information from the research laboratories to the managers in a reasonable length of time and in a usable form is quite difficult and is getting harder with the increase of information available. Keeping track of all this information is becoming impossible (Power 1988, Rajotte et al. 1988, Rauscher 1987, Rykiel et al. 1984). ExS are a natural vehicle to do this especially if they help with interpreting the information and structuring it in a way that is easily used by the managers. ExS can help by taking on the role of librarian to help manage all this knowledge. Duties could include assembling, cataloging, storing and retrieving information, determining the quality of the information, and possibly, determining what information is still missing.

As an aid to forestry education, ExS can educate the general public about forestry issues, train new forest managers and technicians for specific jobs, and aid personnel in their jobs by serving as handbooks, or check lists to increase their performance (Rauscher 1987).

Sample Systems

In forest entomology, ExS have been or are being developed for taxonomic identification, diagnosis, pesticide recommendation, and delivery of simulation models (table 1).

SYTEX (Systematics Expert System) was built to relieve pressure on taxonomists who often are flooded with specimens to identify from across the US and world and to provide an alternative to dichotomous keys (Stone et al. 1986). However, due to the size of the problem of developing the program, only one species was used for the key, <u>Signipbora</u> spp. Ashmead. This highly restricted key may not reduce the taxonomist's work load, but it is a good start in the right direction.

BIPS and ISPBEX were developed at Texas A&M University for diagnosis and prediction of bark beetle related forest management problems (Rauscher 1987).

Table 1.--Expert systems developed for forest insect pest management.

Program	Purpose	Source
INSEX	Recommend insecticides for western forest insect control	Coulson, Robert N., Texas A&M University (unpublished).
ISPBEX	Southern pine bark beetle decision support system	Rykiel, et al., 1984.
SYSTEX	Insect identification	Stone, et al., 1986.
HOPPER	Western rangeland grass-hopper control	Kemp, et al., 1988.
PMDS	Aid in insect population model development	Logan. 1988. Environmental Entomology 17(2).
BIPS	Diagnose & predict bark beetle problems	D.K. Loh, Texas A&M Univ. (unpublished).
PREDICT	Diagnosis problems and assess hazards for red pine insects and disease in Wisconsin	Schmoldt and Martin. 1989.

PREDICT was developed by Daniel Schmoldt of the USFS for diagnosing problems and assessing hazards for red pine insects and diseases in Wisconsin (Schmoldt & Martin 1986,1989). In the diagnosis mode, the user provides information about the stand characteristics and identifies symptoms from a set of menus. The ExS then identifies the causal agent. A second mode, preventive consultation mode, lists various insects and pathogens to be alert for under the stand characteristics identified by the user.

INSEX is an ExS developed by Robert Coulson at Texas A&M University that recommends insecticides for Western forest insect control (Rauscher 1987).

HOPPER is an ExS for western rangeland grasshopper control developed by the USFS (Kemp et al. 1988). The user is questioned about site information, present development stage of the grasshoppers, and the management objective (ie. to save forage), then the system makes a treatment recommendation and gives a benefit/cost ratio for the treatment.

PMDS (Pest Model Design System) is being developed by Jesse Logan of Colorado State University (Logan 1988) as a research tool for entomologists. The goal of the project is to build a program capable of building an insect population model from life history information. The system should reduce the time and expense of developing models that fit in its domain.

What Has Been Learned?

Although ExS have enjoyed success in other fields, they are slow in getting a foothold in forest entomology (Schmoldt and Martin 1986). Two main problem areas slow the process: 1. ExS are not totally suited for natural systems problems and 2. there is a gap in understanding between the researchers/developers and the final users of the systems (technology transfer problems).

Suitability

Research in ExS has a history of less than 20 years and very few systems have been developed in the field of entomology. Rule-based ExS are not well suited to natural systems management for 2 reasons: Rules are not well suited to provide advice in natural system problems and the management process itself is too broad a problem to be suitable for ExS (Coulson et al. 1987). Rule based ExS use inference schemes which are too shallow to provide much more than searches and conflict resolution strategies (Coulson et al. 1987). Application of ExS to resource management is complicated by the existence of multiple experts, uncertainty characteristic of biological and economic data, large data bases, and a knowledge domain that is tied to a changing landscape (Coulson et al. 1987).

Since natural systems are dynamic and not completely understood, scientists tend to try explaining natural phenomena in terms of causa-

tion, not correlation. Rules are not well suited to describe this causative knowledge so deeper knowledge bases are being developed now using structures such as frames and semantic nets to describe the deep knowledge of causation (Coulson et al. 1987). Attempts to apply general theories tend to generate unmanageably large problems for existing ExS technology.

One of the critical elements of ExS is a large knowledge base. Most existing ExS in pest management have been developed for systems well understood and where a lot of data is already in existence such as cotton farming (Lemmon 1986) and bark beetle management (Rykiel et al. 1984). More knowledge on the biology and ecology of forest insects will probably be needed in order to develop good ExS.

It takes a long time to develop an Expert System. Even a prototype of a subset of the problem may take 6 months (Stock 1987). Current projects are getting too large and complex for the traditional 1 student projects (ExS PREDICT took a PhD student 4 years to develop), so the tendency is to skim significant results off the surface of the research and ignore possibilities which lie deeper (Cohen 1987). The temptation is to go for the new and exotic programming at the expense of a completely rounded research project.

Technology Transfer

The inapplicability of ExS to natural systems and insufficient knowledge base are tough problems, but the understanding gap between researchers and users should be easier to solve. Programmers usually do not have to use their programs in the field so in order to develop practical programs they need to understand the user's needs and abilities. In developing the program they should go out to where the programs will be used and interact with the users in their own environment; learn the limitations of the user and understand his problems. The users want information consistent with their conception of the problem. They want it fast, accurate, and obtainable in a user friendly atmosphere without the need of a computer person to help them (Baskerville and Moore 1988). This importance of technology transfer was impressed on researchers at Texas A&M when a southern pine beetle decision support system package was provided to the United States Forest Service but never used (Coulson et al. 1989).

Flexibility

Researchers often get preoccupied with the problem at hand and ignore the needs of the end user. Users are often frustrated when forced into a fixed format by a computer program to answer "the" question expected by the program (Baskerville and Moore 1988). When talking with a human expert, they can ask the questions they want instead of only listening to problems the expert wants to talk about. This flexibility should be written into ExS too.

One person cannot be an expert in all areas of ExS development. Programming, research, the user interface, and system planning are all important. Therefore a committee should work together in developing a program: the management, researchers, and decision makers (Baskerville and Moore 1988, Rajotte et al. 1988).

Future

Future ExS research should concentrated on two main areas: Improving the user interface and adapting ExS technology to problems in working with natural systems.

User Interface

One of the big frustrations users have with ExS is the inability to ask the questions they want. ExS are programmed to answer a narrow range of questions and the user is only given these questions to choose from for his problem. In consulting a human expert, a manager can ask a lot of questions not directly related to the main problem in order to fix in his mind his real problem. The expert can discuss general problems and theories with the manager before focusing on specific solutions to the problem. The interaction is informal and comfortable to the manager. A partial solution to the user interface problem is presented by Rykiel et al. (1984). They developed a program called FERRET, a problem analysis program. It analyzes the user's question and translates it to a form useable to the program. However, its use is still restricted since the user must choose selections from menus given by the computer to present his question instead of simply asking the question in common English like he would to a human expert.

Another problem that needs more work is adapting to the varying levels of interest exhibited by the users. Some users simply want "The Answer" so they can go on with their work. Others wish to play with the system doing "what ifs" and learning why the ExS came up with its answer. Rykiel et al. (1984) describe a decision support system for management of southern pine beetle which has 3 levels of problem structure. In the first level, the user can have direct access to data and models. All inputs are supplied by the user. In the second level, the computer tells the user what models are necessary and what inputs are needed to solve his problem. The user inputs the information and runs the models desired. The third level is the least participate in by the user. The system runs automatically to solve the problem.

Adapting Technology

Expansion of research in use of structures such as frames and semantic nets for knowledge base representation should be productive. Since natural systems are constantly changing and our knowledge and understanding of these systems is increasing, ExS should focus on specific narrow range problems in order to keep them small and easily updated as new knowledge is gained.

Technology Transfer

This leads to our last point, that ExS should be considered as small units to be plugged into a larger decision support system. Some work has already been done in this direction. Hearn and Brook (1988) describe a concept called Integrated Expert Systems. In this system, an executive program manages sub-programs consisting of ExS shell, Data Base Management system, and a system for numerical calculations. The Canadian Forest Service is interested in using ExS in their decision support system called FIDSINFOBASE to handle the nation-wide data base which is integrated with a Geographic Information System (Power 1988). ExS could be plugged in wherever needed and remain invisible to the users.

A general decision support system (DSS) should be developed which accepts ExS modules that can be plugged in and taken out as necessary. This DSS must be implemented by experts in user interface since the user will interact with the DSS program. The ExS plug-in modules would essentially be invisible to the user.

Research staffs are not trained to develop and maintain software to industry standards (Hearn and Brook 1988). Their interest is not focused on the knit-picky stuff like screen color or placement of prompts which are so important for user satisfaction. They are needed for developing prototypes, but the final form of the ExS to be used by managers should be programmed by computer programmers familiar with the industry standards for user interface. These programmers can efficiently present the information of the ExS to the user in a format comfortable to him and carry out the updating of the ExS as new information or a change in knowledge about the problem changes. The word processing industry, for instance, benefitted by programmers who took the initial concept and wrote new word processors that are more user friendly.

Until recently, AI involved large investment of money, time, and personnel, but software shells have been developed that make the completion of a prototype easier (Stock 1987). Researchers using these shells can produce prototype ExS using the most up to date knowledge and technology. They do this well. But psychologists, human factors engineers, sociologists and many others may have significant contributions to the system before it is ready for release to the public (Stock 1987). The developers of the SIRATAC pest management system in Australia learned that releasing software for commercial use involved a lot more than having a working system (Hearn and Brook 1988). They grossly underestimated the staff needed for trouble shooting, user education and maintenance of the computer program. Maintenance problems of the software were compounded by the fact that it was written by biologist researchers who were not programming up to the industry standards. They finally decided to have the program rewritten by industry professionals.

CONCLUSION

Expert systems have been hyped up greatly with implications that they are more efficient, accurate, and consistent than a human expert. Tests have shown that this is indeed often the case, however, rule based ExS are not well suited to many of the problems confronted by pest managers such as those involving controversy or with little existing knowledge. Attempts to force ExS to deal with these problems will end up with frustration. New ExS that are frame based instead of rule based are being developed and have potential use for these problem areas. Where there are not many biological data available or knowledge about the problem solution (i.e., experts do not know what is best or do not agree with each other) then ExS are not appropriate.

ExS technology has been around for several years now and has proven its worth. With the introduction of ExS shells to the market place, development of ExS has been simplified and it is probably no longer a science. There is not a good pay off for universities to develop ExS unless they wish to study the science involved in the background of the development such as efficiency of the systems, cost/benefit analysis, or better methods of knowledge base construction. But once the methodology and utility of ExS has been established, the universities should give the problem to other agencies to do the development work. A technology transfer specialist could then crank out the ExS using the field data, models, and methodologies established by the university researchers.

Where should we go next? Universities should continue to research the biological aspects needed for ExS and develop better methodologies for ExS development. Other agencies should do the actual ExS development with emphasis on sound technology transfer schemes between researchers and users. These agencies will conduct cost/benefit analysis to determine which ExS are worth developing and to what extent. If we all stick to our role in the process and remember the overall goal, we will not let the new technology blind us from reality.

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WILDHARE: A Wildlife Habitat Relationships Data Model for Southwestern Ponderosa Pine[1]

David R. Patton[2] and Kieth E. Severson[3]

Abstract.--Wildlife habitat can be described completely by a system of attributes and relations in a relational database. A habitat relationships data model has been developed for ponderosa pine that includes four basic relations and 33 attributes for 250 wildlife species.

INTRODUCTION

The Forest and Rangeland Renewable Resources Planning Act of 1974 gave the Forest Service responsibility for inventorying the Nation's resources, including fish and wildlife habitat. Because a comprehensive inventory had not been made previously, no detailed guidelines were available on the types or format of data to be collected. In addition, computer software had not been developed to store and retrieve wildlife habitat data. To overcome these problems, the Rocky Mountain Forest and Range Experiment Station developed a wildlife habitat database for the Southwest. This effort resulted in a database (RUNWILD) for a mainframe computer (Patton 1978).

While RUNWILD was a useful tool, it soon became apparent that large capacity microcomputers (>20 megabytes) along with new database software would make data storage and retrieval easier, particularly if the storage scheme conformed to relational theory (Codd 1970). Relational theory guides how data can be depicted and linked in a database. Our paper reports on a general relationships data model linking wildlife species to habitat characteristics in the ponderosa pine forest type.

Southwestern ponderosa pine was selected as a sample forest type for developing a habitat relationships data model because a large amount of wildlife data is available for the type; it is a major commercial species, and the type contains over 250 wildlife species of all life-forms (amphibians, birds, fish, mammals, and reptiles). In developing a relationships model, we interacted with biologists at the region, forest, and district level. Their specific request was to describe the physical characteristics of various vegetation types and to associate each wildlife species with the use of these characteristics for food or cover.

WILDLIFE HABITAT RELATIONSHIPS

Wildlife habitat relationships (WHR) is a systems approach to understanding how animals use vegetation, plants, and landscape features for food and cover. It is a way of thinking about the conditions and processes involved in the complex of plant-animal interactions. WHR programs have been in progress since the late 1970's (Patton 1978, Thomas 1979, Verner and Boss 1980) but associating animals with their habitat is as old as the wildlife profession.

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A general classification of North American mammals and birds by forest habitat preference was developed by Yeager (1961). Birds and mammals were placed into three groups according to whether they are primarily associated with forest or brushland, secondarily associated with forest or brushland, or woody cover not used or only rarely used. The importance of this form of classification is greater today than it was over 40 years ago when Taylor (1940) stated:

"The ecologist capable of arranging all species of mammals and birds, or all vertebrates or animals, into a habitat classification fully considerate of vegetation, terrain, water, elevation, exposure, latitude, and climatic factors would indeed provide a vast fund of useful knowledge."

Because of the large amount of information accumulating in books, journals, and government publications, detailed information is now available to include in a habitat classification scheme as suggested by Taylor.

Describing Habitat

The relationships between animals and habitat can be described completely by using a system of attributes and relations. An <u>attribute</u> is a fact about an inherent physical characteristic, property, measurement, or quality of an animal, plant or habitat. The term <u>relation</u> refers to a collection of facts (attributes) describing the same subject.

One way to understand attributes and relations is to consider a matrix table as the relation and columns in the matrix as attributes (fig. 1A). Cells within attributes contain information about the attribute characteristic. For example, the attributes in a relation could be Species, Vegetation type, Stand structure, Use, and Season (fig. 1B). One row of data for the attribute cells could be deer, ponderosa pine, mature, cover, and winter, in that order.

All the attributes form a relation which might be named "WILDLIFE". Figure 1B provides data indicating that deer and squirrels both use mature ponderosa pine for cover, but squirrels also use ponderosa pine for food. Stand structure can be divided further for additional detail. In this manner, a habitat relationships model can be formulated for many species and many habitat characteristics.

THE PONDEROSA PINE MODEL

For the ponderosa pine forest type and other habitats in general, four

```
==============              A
: RELATION   :
=========================================================
: Attribute  :  Attribute  :  Attribute  :  Attribute :
=========================================================
:   Row ------:-------------:------>      :            :
---------------------------------------------------------
:   cell     :   cell      :             :            :
---------------------------------------------------------
```

```
============                B
: WILDLIFE :
=========================================================
:          : Vegetation  :  Stand  :       :           :
: Species  :    Type     :Structure:  Use  : Season    :
=========================================================
: Deer     :    PP       :  Mature : Cover : Yearlong :
---------------------------------------------------------
: Squirrel :    PP       :  Mature : Cover : Yearlong :
---------------------------------------------------------
: Squirrel :    PP       :  Mature : Food  : Yearlong :
---------------------------------------------------------
```

Figure 1.--Habitat attributes and relations can be defined in tables and columns.

relations form the basic data model: These are SPECIES, HABITAT, ECOS, and AREA (fig. 2) in a database named "WILDHARE"--an acronym for Wildlife Habitat Relationships. Relation names have all capital letters. Attribute names are lower case with the first letter capitalized. Descriptions of relations, attributes and their menus are contained in table 1.

Data in the SPECIES relation applicable to a particular animal are entered only once. The SPECIES relation is also the core relation for WILDHARE because data in the other relations ultimately are linked back to this relation. By entering a species common name in Cname, entries must be made for the other attributes until all the cells in each attribute are filled and one row is complete. For example, the following data could be included in the HABITAT relation:

Cname:	Mule deer
Series:	Ponderosa pine
Reuse:	Cover area
Level1:	Tree stand
Level2:	Dbh 11.0-13.9
Level3:	Dense, little or no understory
Level4:	Single story
Value:	Moderate

WILDHARE DATA MODEL

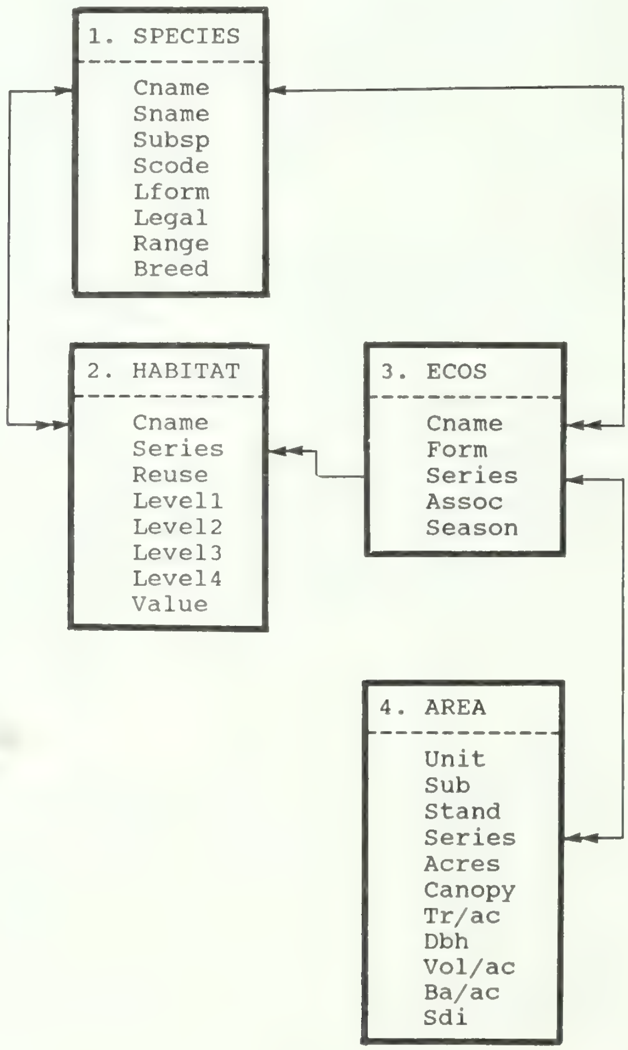

Figure 2.--A habitat relationships data model for the ponderosa pine forest type.

Table 1.--Relations and attributes in WILDHARE.

	RELATION		Attribute[1]	
1.	SPECIES	1.	Cname (30)	(Common name)
		2.	Sname (30)	(Scientific name)
		3.	Subsp (15)	(Subspecies)
		4.	Scode (9)	(Scientific code)
		5.	Lform (2)	(Life-form)
			AM = Amphibian	
			BI = Bird	
			FI = Fish	
			MA = Mammal	
			RE = Reptile	
			IN = Invertebrate	
		6.	Legal (2)	(Legal status)
			FL = Federal listed	
			SL = State listed	
			GA = Game animal	
			FB = Furbearer	
			NG = Nongame	
		7.	Range (15)	(Home range)
			User defined	
		8.	Breed (6)	(Breeding season)
			Spring (Mar-May)	
			Summer (Jun-Aug)	
			Fall (Sep-Nov)	
			Winter (Dec-Feb)	
2.	HABITAT	1.	Cname (30)	(Common name)
		2.	Series (2)	(Vegetation type)
		3.	Reuse (7)	(How physical resources are used)
			Feeding (area)	
			Cover (area)	
			Food (item)	
			Shelter	
			Special (requirements)	
		4.	Level1 (20)	(1st level use)
			Feeding and Cover area	
			Air	
			Opening	
			Topography	
			Tree stand	
			Water	
			Food item	
			Vertebrates	
			Tree-shrub parts	
			Herbaceous parts	
			Aquatic	
			Artifacts	
			Fungi	
			Arthropods	

Shelter
Live tree
Snag
Cave
Log-stump
Ground
Understory
Woody debris
Litter
Rock fissures
Special requirements
User defined

5. Level2 (20) (2nd level use)

Air
Over water
Over vegetation
Over all terrain

Opening
Grass-forbs
Shrubs
Small trees (<5'-1.9)
Single tree

Topography
Cliff-ledge
Talus slope
Canyon bottom
Rock outcrop

Tree stand

Dbh 5'-1.9"	
Dbh 2.0-4.9	(Sapling)
Dbh 5.0-7.9	(Small tree)
Dbh 8.0-10.9	(Small-medium tree)
Dbh 11.0-13.9	(Medium tree)
Dbh 14.0-16.9	(Medium-large tree)
Dbh 17.0-19.9	(Large tree)
Dbh 20+	(Old trees, Old growth)

Water
Seeps-springs
Streams-rivers
Ponds-lakes
Bank
Marsh
Rain pools

Vertebrates
Amphibians
Birds
Fish
Small mammals
Medium-large mammals
Reptiles

Tree-shrub parts
Cones
Twigs
Buds
Pollen
Leaves
Roots
Needles
Acorns
Bark

Soft fruits
Nuts
Seeds
Sap

<u>Herbaceous</u>
Flowers
Shoots
Nectar
Misc. vegetation
Honey
Grass
Forbs
Woody stems (browse)

<u>Aquatics</u>
Submergents
Emergents
Algae
Plankton
Aquatic insects

<u>Artifacts</u>
Carrion
Eggs
Bones
Garbage

<u>Fungi</u>
Mistletoe
Hypogeous fungi
Shelf fungi

<u>Arthropods</u>
Flying insects
Insect larvae
Crawling insects
Crustaceans
Snails
Spiders
Worms

<u>Shelter</u>
Nest
Bed
Burrow
Roost
Cavity
Under bark
Bunchgrass
Brush

6. Level3 (15) (3rd level use)

<u>Opening</u>
Dry
Moist-wet

<u>Water</u>
Warm
Intermediate
Cold

Tree stand
THa = Thin, little or no understory
THb = Thin, understory of grass-forbs
THc = Thin, understory of shrubs
THd = Thin, understory of small trees
MOa = Moderate, little or no understory
MOb = Moderate, understory of grass-forbs
MOc = Moderate, understory of shrubs
MOd = Moderate, understory of small trees
DEa = Dense, little or no understory
DEb = Dense, understory of grass-forbs
DEc = Dense, understory of shrubs
DEd = Dense, understory of small trees

7. Level4 (15) (4th level use)

Opening or Shelter
Sandy soil
Rocky soil
Moist soil

Tree stand
Single (story)
Multiple (story)

Water
Milky-muddy

8. Value (1) (Degree of preference when available)

5 = High use
4 = Moderately high
3 = Moderate
2 = Moderately low
1 = Low
* = Used (value unknown)

3. ECOS

1. Cname (30) (Common name)

2. Form (2) (Vegetation formation)

FO = Forest

3. Series (2) (Vegetation series).

PP = Ponderosa pine

4. Assoc (2) (Association with Series)

HA = Considered typical habitat
FR = Occurs but is fringe habitat
RA = Rarely occurs in type

5. Season (2) (Presence in SERIES)

YL = Yearlong resident
SU = Summer
WI = Winter
SM = Seasonal movement (up-down slope)

4. AREA (To be developed for each local area)

DEFINITIONS

Opening: <10% canopy, or vegetation not in trees

TH =	Thin:	11-40% overstory
MO =	Moderate:	41-70% overstory
DE =	Dense:	>70% overstory

a = Little or no understory
b = Grass-forb
c = Shrubs
d = Small trees (5' ht-1.9" Dbh)

* = This symbol can be used in the database for any attribute that is unknown or not yet determined.

[1]Number in parenthesis is number of spaces allocated to attribute.

Text data are generally used to describe attributes but in some cases codes are used instead, for example, PP = ponderosa pine, FO = forest, etc. Entries or values are selected from a menu for each attribute. In developing attribute characteristics, statements are used that describe physical habitat either quantitatively or qualitatively. Other attributes (Level5, etc.) can be added if more detail is needed. In the example above, values for all 8 attributes contribute one row of information, in one relation.

The ECOS relation (ecosystem) provides information on the adaptability of species to different vegetation types. Since a given species can be found in several types, the ECOS relation will contain duplicate data for some attribute cells but no two rows of data will be identical--that is, one attribute cell will always be different in each row.

In the AREA relation, all attributes are associated with Stand. Stand is part of a subunit (Sub) and subunit is part of another unit (Unit). As a result of these identifiers, numerical totals such as volume per acre, basal area per acre, or total acres can be computed for a management unit or subunit. Computations and statistical analysis can be made for the other quantified attributes.

How The System Works

Relations have key attributes for retrieving data from more than one relation at the same time. Data from one relation is linked to data in other relations by direct and indirect routes. Direct links between SPECIES, HABITAT, and ECOS are provided by Cname and between HABITAT, ECOS, and AREA by Series. An example of a question that can be asked using the direct link is: What endangered species (Legal and Cname in SPECIES) are found in ponderosa pine yearlong (Cname, Series and Assoc in ECOS)?

Since the Series attribute is in HABITAT, ECOS and AREA, and Cname is in SPECIES, HABITAT and ECOS then SPECIES and AREA are indirectly linked through either HABITAT or ECOS. This indirect link provides the route for associating data in SPECIES with data in AREA. For example: What wildlife species (Cname in SPECIES) should be found in a management unit (Unit in AREA) containing ponderosa pine (Series in ECOS)? Data can also be retrieved from one relation. For example, the statement to be made from the one row of data in the HABITAT relation defined previously is: "Dense, single story ponderosa pine stands, ranging from 11-14 inches dbh, with little or no understory have a moderate cover value for mule deer".

In the past we have used a species code (Scode) developed from the scientific name as a unique link between relations because of a need to conserve space. Since space is no longer a critical problem for large capacity microcomputers, common name (Cname) is a good link to use because it is more meaningful to biologists than a code. Scode is included in the SPECIES relation for reference.

The relationships data model is to be used with relational database

software.[4] Information is retrieved or manipulated from WILDHARE using commands common to databases conforming to relational theory. While the WILDHARE habitat relationships model contains only four relations, its utility is in the combinations of attribute characteristics associating an animal with physical habitat and the value of that association if it is known.

FUTURE DEVELOPMENT

The basic habitat relationships data model will need refining as we add more wildlife species and their physical habitat requirements. Our goal is to include wildlife species for other forest types in the Southwest. Future development of WILDHARE will be to include it as a module for the Decision Support System (DSS) now being developed in the School of Forestry at Northern Arizona University (Covington et al. 1989). The DSS incorporates a GIS and a growth and yield model that will make WILDHARE a practical tool to compare management alternatives.

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[4]WILDHARE was formatted in Microrim's R:Base for DOS with artificial intelligence software (Clout).

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Rocky Mountains

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**General Technical
Report RM-186**

The Declining Even Flow Effect in the National Forest Planning Process

**Brian M. Kent
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USDA Forest Service
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January 19

The Declining Even Flow Effect in the National Forest Planning Process

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Abstract

McQuillan (1986) has identified what may be a serious flaw in the planning process used by the USDA Forest Service. The problem, which McQuillan called the declining even flow effect (DEFE), can occur during repeated iterations of a planning process using a timber harvest scheduling model whose objective is wealth maximization subject to nondeclining yield constraints. The DEFE creates a situation in a sequence of plans over time where the first-period harvest level declines below that attained for previous planning iteration analysis. This report addresses the relationship between the process used by the Forest Service to develop FORPLAN models and the DEFE. An example using Kootenai National Forest planning documents illustrates the highly constrained nature of Forest Service planning models. The effect of these constraints and other characteristics of FORPLAN models on the DEFE is examined. Two items common to nearly all forest planning models—a land base that is not entirely old-growth and constraints to assure that the 40-acre clearcut limit is not violated—caused a large reduction in the DEFE observed in a FORPLAN version of McQuillan's case study model. However, one characteristic of Forest Service planning models, the use of intermediate harvest options, which plausibly could have reduced the DEFE, did not. The opportunity cost associated with imposing a first-period harvest floor to eliminate the DEFE was also evaluated. The major conclusion of the study is that the regulations, initial conditions, and the FORPLAN model formulations all tend to reduce the likelihood and magnitude of the DEFE.

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The Declining Even Flow Effect in the National Forest Planning Process

Brian M. Kent, James B. Pickens, and Peter G. Ashton

INTRODUCTION

The Forest Service is currently nearing completion of he first iteration of planning mandated by the National 'orest Management Act (NFMA) of 1976 (P.L. 94–588). ıfter the press of deadlines and the conflict created by pecific resource decisions has abated, an important exənsion to the planning process will be to evaluate the lanning approach applied and, specifically, the anaytical methods used. Much of the recent technical literture concerning the use of linear programming in arvest scheduling models has dealt with topics that are entral concerns of the forest planning process (e.g., Hof t al. 1986, 1988; Hoganson and Rose 1987; Paredes and rodie 1988; Pickens and Dress 1988).

The research presented in this report addresses a paraoxical phenomenon originally identified and demontrated by McQuillan (1986), which he called the eclining even flow effect (DEFE); namely, a planning rocess that is repeated periodically (e.g., every 10 years ı the Forest Service case) and is conducted using a harest scheduling model with a wealth (present net value) ıaximizing objective and nondeclining yield constraints oes not generally lead to a nondeclining sequence of mber harvests. The divergence from nondeclining yield ccurs when the forest plan is revised and the chosen arvest level in the first cutting period is less than the arvest implemented under the previous plan. The DEFE vould be expected to be most severe for a forest made p entirely of old-growth stands. Under this scenario, ıe model would choose to harvest the most profitable tands early in the planning horizon, while deferring arvest on less profitable stands until later. This harvestıg sequence is dictated by the low or negative growth ıte of old-growth stands, the effect of discounting, and ıe opportunity cost associated with highly productive ınds being occupied by stands with little or no growth.

In addition, it is likely that unprofitable stands will e scheduled for harvest at some point in the future to ıtisfy the nondeclining yield constraints. This occurs ecause the discounted cost of scheduling negatively alued stands several decades into the future is more ıan offset by the increased value associated with harесting the higher valued stands during the early periıds of the planning horizon. Essentially, the model can hoose to bridge the gap between accelerated early harəst of profitable existing stands and future harvest of generated stands with timber that cannot be harvestl at a profit.

The declining harvest level between time periods ocırs when the forest plan is revised during a future iterion of planning. At this point, some of the profitable harvests have been implemented, which leaves less short-term gain to be balanced against future losses resulting from cutting unprofitable stands. This leads to a first-period harvest calculated for the revised plan that is less than the harvest in the previous cutting period. Thus, the Forest Service is presented with two options, either (1) to incur unplanned, immediate, and repeated departures, or (2) to place a floor on first-period timber harvest that will lead to harvest levels higher than the economics in the harvest scheduling model would otherwise indicate. Either option is difficult to defend, and the option of repeatedly applying a constraint on first-period harvest would lead to the early harvest of the negatively valued stands in some later planning iterations. The concern for the agency as it concludes the first iteration of planning is the extent of the DEFE that can be expected as future iterations of planning and analysis are conducted.

The Forest Service planning process is distinctly different from the situation presented in the case study and discussion of McQuillan in three ways. The first and most important difference is that McQuillan considers a timber only, profit-oriented enterprise with nondeclining yield constraints, while the multiple-use requirements of the Forest Service planning process result in the imposition of numerous additional constraints on the individual FORPLAN models. Although these constraints vary widely from model to model, certain requirements are represented similarly in most models and may affect the DEFE. In addition, special constraints are often applied to address specific issues on each forest, and these constraints may also affect the DEFE. Examples include constraints imposed to meet management requirements for a wide range of predominantly nonmarket concerns (e.g., sediment, erosion, scenic attributes), endangered species (e.g., grizzly bear, spotted owl), and those designed to address multiple-use issues specific to a forest (e.g., wilderness areas, recreational development).

The second distinction between McQuillan's (1986) case study and forest planning models is the set of options available for management of the land base. McQuillan considered only clearcutting prescriptions with no intermediate cuts or alternative regeneration harvests. However, in many forest planning models used by the Forest Service, shelterwood and selection options are also considered. In addition, thinnings are incorporated in many prescriptions, and these intermediate cuts can result in increased flexibility for satisfying nondeclining yield constraints within a given model. It is not immediately clear if the presence of intermediate cuts will increase or reduce the DEFE—this depends on

the economic characteristics of the thinnings, the relative numbers of positively and negatively valued stands available, and the magnitude of present net value associated with the timber land base. One final consideration is that, even though a specific stand may be quite valuable, harvesting on certain lands may either be spread over several periods or delayed until later periods because of considerations such as road access.

The third difference between McQuillan's (1986) example and an average forest planning application is the age structure of the initial forest. McQuillan considered a forest that was entirely old-growth, an age structure never encountered in national forests. Most forests have been managed in the past to some extent, and the implicit goal of previous management was to regulate the forest. This goal resulted in forests where the commercial forest base has undergone harvesting for several decades. Although the areas harvested would be expected to be somewhat smaller than those resulting from regulation via area control, substantial portions in many cases have already been converted from old-growth to managed stands. In addition, ecological perturbations such as forest fires and pathogen infestations often add age diversity to the as yet unmanaged portion of the forest. As can be seen in Hof et al. (1986), even relatively small shifts in initial age structure of the forest can result in significant shifts in land allocation when nondeclining yield constraints are applied.

FORPLAN MODEL FACTORS AFFECTING THE DEFE

The Highly Constrained Nature of FORPLAN Models

To help understand the highly constrained nature of forest planning models developed using FORPLAN, consider the following example based on the Kootenai National Forest planning analysis. Figure B-14 (Haugen 1987) of the forest's planning document will be used to facilitate this discussion and is reproduced here as figure 1. This figure presents the changes in present net value observed when required sets of constraints are added and removed during the process of FORPLAN model development. Concentrating on the central portion, our analysis starts with an unconstrained model solution having a present value of $2,083 million, and progresses down the page to alternative A with a present value of $1,143 million, indicating that the constraints needed to represent Forest Service regulations in the analysis collectively reduce present value by 45%. Thus, such factors as nondeclining yield, restricting regeneration harvests to occur at or after 95% of culmination of maximum mean annual increment, and minimum management requirements (MMR's) have a large influence on the forest's management. However, the important question is whether the DEFE is likely to be fundamentally changed by the constraints applied, or whether the constraints simply reduce the DEFE in proportion to the reduction in harvest levels.

Our discussion focuses on the minimum management requirements applied to this model and on their expected impact on the DEFE. The first MMR applied related to grizzly bear habitat maintenance, which required leaving large areas undeveloped. If the model was allowed to select the location of these areas, lands with poor timber economic potential would likely be allocated to this use because of the wealth-maximizing objective. This would decrease the number of negatively valued stands available in later periods for balancing early profitable harvests. Because this "balancing" is the main cause of the DEFE, these constraints have the potential to reduce both its size and magnitude.

The next MMR's considered in figure 1 address soil and water issues. These restrictions on land use have a very high opportunity cost of $566 million. Many of the restrictions in this class would involve either restrictions on certain lands (e.g., stream buffers restricted from harvest) or restrictions concerning spatial and temporal applications of allowable timber management practices (e.g., spatial and temporal separation of harvesting activities). These restrictions have the potential to significantly reduce the DEFE, because the spatial and temporal limitations would prevent a contiguous block of sensitive land from being completely harvested in a single cutting period (decade). Although specific analysis areas in many FORPLAN models are not necessarily contiguous, they generally contain large contiguous areas. The constraints would tend to spread the harvests out over several cutting periods on these areas. In addition these sensitive areas would tend to be near streams, and are often comprised of high-value land whose early exploitation is required for a large DEFE. On the other hand, an examination of McQuillan's case study shows that most of each analysis area was clearcut in a single cutting period. Thus, his case study has far more opportunity to exploit the differences between stands than do forest planning models.

The magnitude of lost present net value associated with the final MMR category, old growth/diversity, is quite small ($31 million), and it is not clear if these constraints will reduce the DEFE.

The final point of interest in figure 1 is the reduction in present net value associated with application of nondeclining yield constraints. When these constraints are applied prior to the MMR's, a high opportunity cost is observed ($202 million), while the opportunity cost is much less when the constraints are applied after the MMR restrictions ($28 million). Clearly, in objective function value terms, the MMR restrictions impact harvesting in a way similar to that of nondeclining yield. This similarity arises primarily from the spatial and temporal dispersion of management actions imposed by the MMR restrictions. This would suggest that the DEFE would not be expected to be extreme in this example.

Note that the above discussion deals with the results of only one forest planning analysis and model. However, similar constraint sets are common to most forest planning models, and some of these constraints will always distribute the liquidation of contiguous forest units over time.

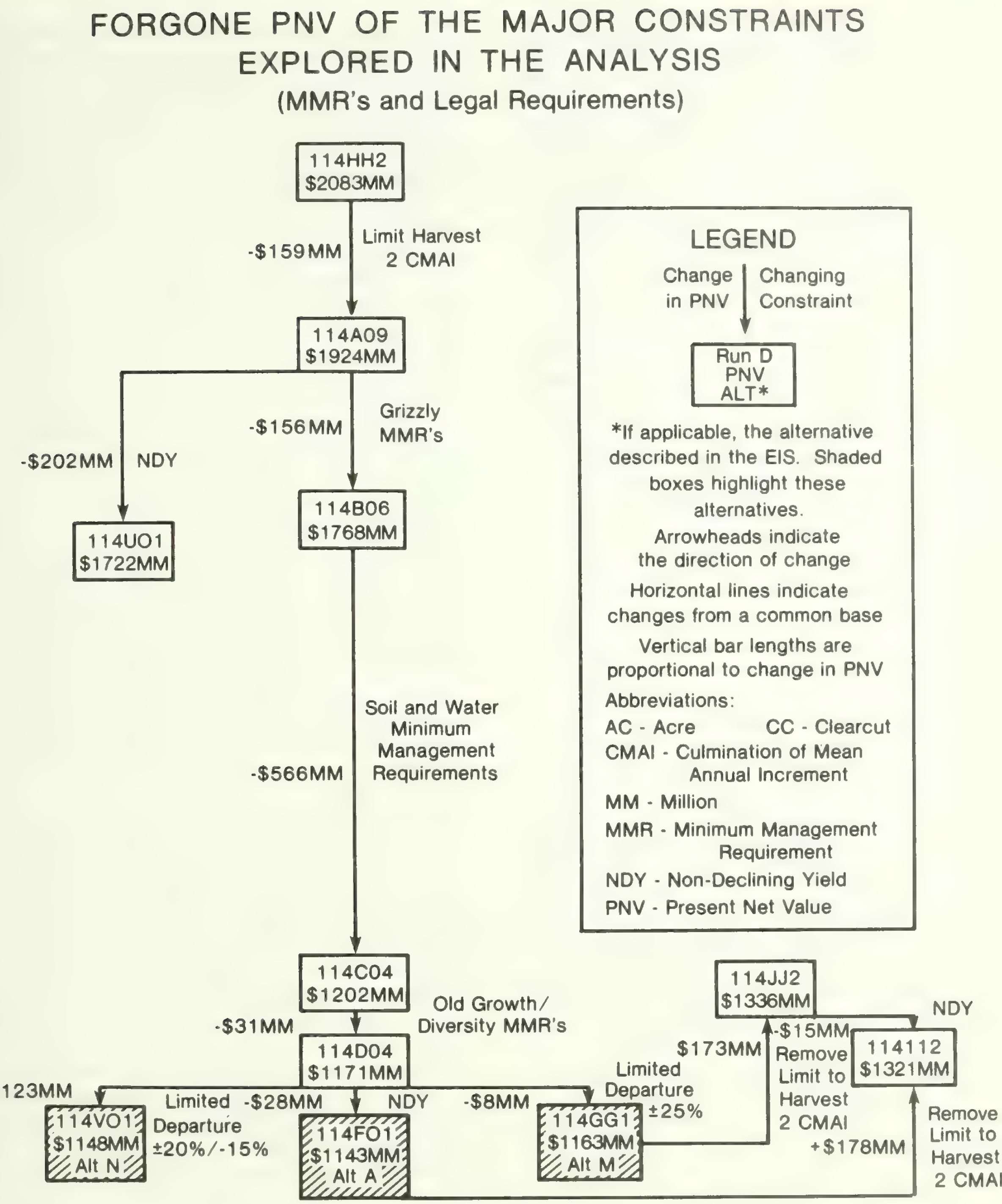

Figure 1.—Figure B-14 (part 1) from the Kootenai National Forest planning documents (Haugen 1987). This figure demonstrates the opportunity cost associated with constraint sets applied at various levels of the FORPLAN modeling process.

Additional Restrictions and Constraints with Direct Effects on the DEFE

There are other forest planning restrictions and constraints that affect the DEFE. Before running FORPLAN, planners are required to analyze the economic efficiency of alternative prescriptions on all classes of timberland. Lands considered uneconomical to harvest may be excluded at this time. In addition, the amount of negative value harvesting on any analysis area may be restricted in any given cutting period within FORPLAN models.[2]

[2]Jim Merzenich of the Region 6 Regional Office indicated that these options or similar methods have been used in forest planning situations in Forest Service Regions 1 (Northern) and 6 (Pacific Northwest) to restrict the choice of negatively valued timber harvests in the future.

Another reality of forest planning is that the current situation sometimes dictates much of what will be implemented in the first decade, and consequently, the planning process creates a framework where near-term options often are very limited. One example of near-term restrictions is the current extensive salvage and sanitation harvest of pine bark beetle mortality in many Rocky Mountain forests. Other examples are the explosion of Mount Saint Helens and the catastrophic fires of the summer of 1988. In such cases, management actions during the first decade are restricted to the point that DEFE is not a concern.

The only important constraints remaining to be discussed in terms of their impact on the DEFE are those included to assure that the maximum size of a regeneration harvest (e.g., clearcut, shelterwood, or seed tree) is 40 acres or less (100 acres or less in Alaska). These constraints appear in most FORPLAN models because they are required by the NFMA. They can be formulated in a variety of ways, the most common being to require that not more than a certain amount of each analysis area can be regeneration harvested in a certain cutting period. If analysis areas are spatially located in large contiguous blocks of land, this restriction is typically represented by constraining each analysis area so that not more than 25% of it can be regeneration harvested in any cutting period (decade). If the analysis areas occur in somewhat smaller blocks of land, then the area allowed to be regeneration harvested in any cutting period is increased somewhat. Note that not all of an analysis area need be in one contiguous block for this approach to be appropriate; it is sufficient for the analysis area to be comprised of several relatively large blocks. Some areas where regeneration and stand development are sufficiently slow require inclusion of either more restrictive constraints or more restrictive timber prescriptions to limit harvesting in a cutting period because of adjacent actions in previous or future cutting periods. These constraints, taken as a group, should significantly reduce the DEFE by rationing the harvest of each analysis area over several decades.

OPTIONS FOR SELECTING A CASE STUDY

Two very different options are available for developing a case study to assess the impact of the DEFE in forest planning:

1. Select one (or possibly more if resources permit) test case national forest FORPLAN model, and simulate the process of repeated iterations of planning with the model. This approach would be most useful for measuring the DEFE on the test case model.
2. Select a case study model that is considerably simpler than a real forest planning model, and simulate certain aspects of FORPLAN model development in order to measure their impact on the DEFE. This approach would be most useful for developing a more complete understanding of the relationship between the process of forest planning model development and the DEFE.

The main advantage of the first approach is that the study would be able to make a very specific statement concerning the magnitude of the DEFE for the selected forest. This advantage would, however, be purchased at a high price. Some of the studies done by the Policy Analysis Staff have used actual forest models successfully (e.g., Ashton 1985). Experience indicates that studies like this, where few data values are changed and feasibility cannot be violated, can be conducted in a straightforward manner. However, if extensive revision of the FORPLAN data sets is involved, the process becomes expensive, time consuming, and the completion of the project becomes problematical. Such would be the case if one were to iteratively simulate the implementation of forest plans over enough cycles of planning to understand the magnitude of the DEFE for a forest.

In addition to these general concerns, several specific questions must be addressed. First, in the selection of a test case model, should one attempt to select a case study which demonstrates an extreme potential for the DEFE, or one that has an average DEFE? Second, even if this concern is resolved, how does one identify which situation is present given the current level of understanding of the DEFE? Clearly, the constraints applied to the model will be important. The relationship of profitable and unprofitable harvests available is also an important factor. A study like the one proposed by the second option would help to resolve some of these uncertainties. In the final analysis, no matter which type of case study forest one selects, it still is a sample of only one observation, and thus any conclusions would be of limited applicability.

Even if these specific questions can be resolved, the technical problems associated with updating large FORPLAN data sets are formidable. Substantial changes to several sections of the input data would be needed. The land base would need to be entirely updated between runs in order to reflect the results of the activities conducted during the first period of plan implementation. This process would lead to a proliferation of both analysis areas and prescriptions, resulting in successively larger, more complex, and more expensive models. Yield streams and economic data would require updating. In addition, constraints are often applied for the first two cutting periods in FORPLAN models, and it is not clear how or if these constraints should be modified or eliminated as one proceeds through repeated simulation of planning cycles. Clearly, by the time all of the updating is done and certain assumptions of necessity are included in the updating process, it would be difficult to separate changes that occur because of these assumptions from changes that can be attributed to the DEFE.

The second option available to study the DEFE would directly address the question, What are the implications for the DEFE of the way FORPLAN models are formulated? Both the situations on forests and the FORPLAN models constructed to mathematically represent these situations are extremely variable. Also, it is clear that certain frequently used constraints, options, and existing conditions can significantly affect the magnitude of the DEFE. With the second option, a large number of

mulations would be possible with a small test case iodel, and the resulting analysis would have general oplicability to the expected impact of situations (e.g., onstraint sets) common in forest planning models. Ad-itional advantages are that the cost would be low, and roblems with ambiguity and assumptions associated ith problem updating would be minimized. For these easons, we selected the second option for this study.

CASE STUDY

Description

The case study model presented by McQuillan (1986) or the original analysis of the DEFE was selected as the andard of comparison for our analysis. The model ontains five analysis areas, each with 1,000 acres and aving identical site productivity and stocking. The pre-criptions allowed are clearcutting and minimum level ianagement. The forest currently consists of old-growth ands containing 15,000 board feet (mbf) per acre, and o net volume change is expected. In the model, regener-ted stands are expected to have no volume until age 70, which time the volume becomes 25 mbf per acre and oes not change as the stands age. The price is current- $300 per mbf, but is expected to increase by 1.5% per ear for the next 50 years, after which price will not iange. The only difference between analysis areas is ie cost associated with timber harvesting. The harvest osts are $170, $290, $410, $530, and $650 per mbf for ialysis areas 1 through 5, respectively. These costs are ssumed to be the same for both old-growth and regener-ed stands. The discount rate is 4%, and all costs and venues are assumed to occur at the midpoint of the cut-ng period. Land area, nondeclining flow, and a limit harvest below an exogenously calculated long-run sus-ined yield level were the only constraints included in IcQuillan's example. The objective was to maximize resent net value over a 12-cutting-period planning orizon. Each cutting period is 10 years long.

Analysis areas 1 and 2 always provide positive value arvests; analysis areas 3 and 4 start with negative value arvests but become positive in the third and fifth de-ide, respectively, because of rising product value; anal-sis area 5 can never be harvested profitably. See IcQuillan (1986) for a more complete financial analy-s of the problem.

The same problem was formulated for this study using ORPLAN Version 2 (Johnson et al. 1986, Johnson and tuart 1987, Robinson et al. 1987). Because of two differ-ices between the harvest scheduling model used by IcQuillan and FORPLAN, exact reproduction of IcQuillan's results was not possible. First, both models nployed a long-term sustained yield cap, but the iethods used to calculate the cap were different. Sec-nd, there were minor discrepancies in the timing hoices generated by the two models. This FORPLAN odel will be referred to as the "base model."

Table 1 compares McQuillan's model and the base odel for eight iterations or rounds of planning. The first-period harvest level is reported for each planning iteration for each model. The volume reduction observed for each occurrence of the DEFE (departure) is also reported. The main difference between the results of the base (FORPLAN) model and McQuillan's model are that two departures (in planning iterations 3 and 4) in McQuillan's model are replaced by one much larger departure in the base model (planning iteration 4). In addition, the base model has slightly greater total DEFE (ΣDEFE = 9,949 mbf) than McQuillan's model (ΣDEFE = 8,743 mbf). Otherwise, the two models provide very similar results.

Table 1.—First-period comparison of McQuillan's model and the base model developed using FORPLAN version 2 (volumes are mbf).

Planning iteration	FORPLAN base model		McQuillan model	
	Harvest	DEFE	Harvest	DEFE
1	10,000		10,000	
2	9,290	710	9,522	478
3	9,298		8,117	1,405
4	5,964	3,334	7,047	1,070
5	10,440		10,308	
6	10,450		10,395	
7	4,545	5,905	4,605	5,790
8	16,429		15,407	
Total DEFE		9,949		8,743

Simulation Characteristics

In all FORPLAN forest planning models, one can find examples of constraints and initial conditions that affect the temporal and spatial application of harvests. In this study, three factors present in all (or at least nearly all) FORPLAN models that might be expected to interact with the DEFE are selected for analysis with the case study model:

1. Constraints to assure the maximum regeneration harvest size of 40 acres for both existing and regenerated stands.
2. A modification of the land base to reflect limited previous harvesting.
3. More realistic yield streams with thinning options.

This and all other analyses described below are carried out for eight planning iterations.

Regeneration Harvest Size Constraint

To satisfy the NFMA requirement that all regeneration harvests be not larger than 40 acres, a set of constraints was applied to the base model which guarantee that not more than 25% of an analysis area could be harvested in any one cutting period.[3] This constraint set is reason-

[3] *Jim Merzenich of the Region 6 Regional Office of the Forest Service indicated that, in his experience, these represent a lower limit to the spatial and temporal dispersion constraints applied in forest planning models for Forest Service Regions 1 (Northern) and 6 (Pacific Northwest). Although these constraints often do not occur in exactly this form, the net effect is the same.*

able if analysis areas occur in large contiguous blocks and it is widely applied in forest planning models.

The results of these simulations (table 2) show that the spatial dispersion constraints have a major impact on the DEFE. The base solution has three expressions of the DEFE, during planning iterations 2, 4, and 7, for a total of 9,949 mbf. When the spatial dispersion constraints are applied there is only one expression of the DEFE, in planning iteration 6 (2,580 mbf). The fact that the departure occurs far into the future when the spatial constraints are applied is both predictable and important. It is predictable because spatial constraints ration each analysis area's harvest over at least 4 cutting periods. It is important because a great deal of uncertainty is associated with events more than 50 years in the future even without the DEFE. In other words, the significance now of a DEFE that far into the future may not be all that high.

The columns for total revenue also show a more stable pattern with the spatial dispersion constraints than in the base runs. This suggests that, although (as shown in table 2) the dispersion constraints are quite expensive in present value terms, they assist not only in distributing harvesting activities spatially, but also in distributing revenue temporally.

Previous Harvesting Constraints

Few, if any, national forest planning units exist where previous harvesting has not occurred. In addition, because of natural catastrophes such as disease and fire, forests composed entirely of old-growth seldom occur. These factors can have a significant impact on the DEFE. Recall that if nondeclining yield constraints are imposed, the DEFE occurs when a harvest scheduling model uses negatively valued harvests to bridge the gap between profitable early old-growth harvests and profitable regenerated stands. This gap can also be bridged in mixed age forests by harvesting stands that are young at the start of the planning horizon.

Prior harvesting activities that modify the age structure of the forest will likely display additional characteristics that will reduce the DEFE. The areas where previous harvests have occurred will tend to both produce more valuable timber and have lower harvesting costs, thereby interacting with the DEFE in two ways: (1) the number of available high-value, old-growth stands will be reduced, thus reducing the potential for the DEFE to occur; and (2) the stands harvested before the first planning iteration would tend to be more productive and thus have shorter rotation ages for the regenerated timber. These shorter rotation ages would provide harvests sooner, thus tending to fill the gap between old-growth and regenerated stands.

To simulate this situation, the land base in the base model was modified to reflect assumed harvesting of 200 acres of each of the most profitable analysis areas (1 and 2) in each of the two preceding decades. This harvest of 400 acres per decade is significantly less than the amount that would be cut under strict area control (where 5,000/7 = 714 acres final harvested per decade) and also less than the amount that could be cut if only lands that are expected to be profitable in the future are harvested (where 4,000/7 = 571 acres final harvested per decade). Selecting the previous harvests from only the better sites is consistent with the idea of previous exploitation, conducted under the premise that meeting timber harvest targets while operating within a budget was the driving objective. Previous harvesting for only two decades was assumed because it is representative of conditions on many national forests.

Table 3 gives the results of the simulations with the land base modified and, to facilitate comparison, includes the results of the base model. The modified land base runs contain two departures attributable to the DEFE: one in planning iteration 2 (1,222 mbf) and one in planning iteration 7 (1,175 mbf), with a total DEFE of 2,397 mbf. This modification of the base model, which imitates existing conditions on many forests, shows considerable reduction of the DEFE, especially late in the conversion process. On the other hand, the harvest

Table 2.—First-period comparison with spatial dispersion constraints added (volumes are mbf).

Planning iteration	Spatial dispersion model			FORPLAN base model		
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]	DEFE
1	6,068	0.651		10,000	1.532	
2	7,500	1.088		9,290	1.389	710
3	7,500	1.540		9,298	1.351	
4	10,080	2.169		5,964	0.736	3,334
5	10,080	1.636		10,440	1.840	
6	7,500	1.209	2,580	10,450	1.058	
7	7,500	1.209		4,545	0.460	5,905
8	13,875	4.584		16,429	7.575	
Totals	70,111	14.086	2,580	76,416	15.941	9,949
Revenue present net value		3.023			3.597	

[1]*Revenue is net first-decade revenue reported in millions of dollars.*

Table 3.—First-period comparison of the base model with the same model with a modified land base to reflect previous harvesting (volumes are mbf).

Planning iteration	Modified land base model			FORPLAN base model		
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]	DEFE
1	6,000	0.919		10,000	1.532	
2	4,778	0.767	1,222	9,290	1.389	710
3	7,215	1.048		9,298	1.351	
4	7,222	0.685		5,964	0.736	3,334
5	14,259	1.736		10,440	1.840	
6	14,895	4.507		10,450	1.058	
7	13,720	4.390	1,175	4,545	0.460	5,905
8	13,720	4.988		16,429	7.575	
Totals	81,817	19.040	2,397	76,416	15.941	9,949
Revenue present net value		3.173			3.597	

[1]*Revenue is net first-decade revenue reported in millions of dollars.*

Table 4.—Yield table to demonstrate the impact of thinnings and more realistic yield streams on the DEFE (volumes are mbf).

Age	Stand volume (no thinning)	Thin every 20 years		Thin every 30 years	
		Thin	Volume	Thin	Volume (before thinning)
10	0		0		0
20	0		0		0
30	10		10		10
40	13		13		13
50	17	4	17		17
60	21		17	5	21
70	25	4	21		20
80	28		21		24
90	31	4	25	5	27
100	34		25		25
110	36	4	28		28
120	38		27	5	31
130	39	4	30		29
140	40		29		32

cline in the second planning iteration could be of con-lerable significance. As will be seen below, occur-nces of the DEFE are delayed when a more realistic rest planning situation is simulated; at least this was for this case study.

;ing Alternative Yield Streams

Whereas one would expect that the two modifications the base model discussed above would reduce the EFE, the effect of more realistic yield streams (i.e., ose showing net growth) or of prescriptions that in-ude thinning are less predictable. On many national rests, thinnings are used extensively on the more oductive stands. The model could conceivably use ese intermediate harvests to bridge the gap between rly profitable harvests and the final harvest of regener-ed stands, resulting in a smaller DEFE. These thinnings so could be used to raise harvest levels during all planning iterations while leaving the DEFE essentially unchanged. In addition, unprofitable thinnings could result in an even greater DEFE. For these reasons the simulations presented in this section should be viewed as an example rather than as a general evaluation of the impact of thinnings on the DEFE.

Old-growth yields were not changed. We still assumed that the forest is composed of stagnant stands with inventory of 15 mbf per acre. The new yield streams for regenerated stands, all showing growth over time, are presented in table 4. The nonintensive management regime produces 10 mbf at 30 years, 25 mbf at 70 years (the same as in the original example), and reaches 40 mbf at 140 years. This yield stream reaches maximum mean annual increment at 70 years (the same as in the original example), the youngest age for which regeneration harvests are defined. Two thinning regimes are included. One has initial entry at age 50, additional entries every 20 years, and 4 mbf harvest per entry. The other thinning regime has initial entry at age 60, additional

entries every 30 years, and 5 mbf harvest per entry. The minimum rotation age is 70 years in both regimes. The price of sawtimber was unchanged from previous simulations, and cost of thinning harvest was assumed to be 20% higher than clearcut cost, which was also unchanged.

The results of simulations using these yield estimates and prescription options are presented in table 5. This example clearly demonstrates that profitable thinning options can be selected to bridge the gap without necessarily reducing the DEFE. The harvest in the later planning iterations (4–8) is increased somewhat, and the total DEFE of 10,749 mbf is slightly higher than the base model DEFE of 9,949 mbf.

A More Realistic Forest Planning Model Simulation

To more closely simulate a realistic forest planning model, the first two modifications (harvest size constraints and previous harvesting) were incorporated in the same model. The third modification was not included because of the arbitrariness of using any specific yield stream and its associated cost assumptions. While this model more closely corresponds to an actual planning situation, it is important to recognize that, in reality, both many more types of constraints and a land base with more age, species, and productivity classes would be encountered.

The simulation results for this model are presented in table 6. The DEFE did not occur in this model until planning iteration 7, and then it was quite minor (212 mbf). In planning iteration 8, a relatively severe DEFE of 3,748 mbf occurred, after which (not shown in the table) the harvest returned to a level just below that of planning iteration 7. The sharp drop in planning iteration 8 resulted because of two factors. First, a 250-acre analysis area was the only land harvested in planning iteration 1, so only 250 acres of regenerated stands were available for harvest seven decades later. Second, the acres regenerated before the first iteration of forest planning had been harvested in iterations 6 and 7, thus leaving no previously regenerated lands available for harvest.

Table 5.—First-period results of model simulations using modified yield information (volumes are mbf).

Planning iteration	FORPLAN base model		Modified yields model	
	Harvest	DEFE	Harvest	DEFE
1	10,000		10,000	
2	9,290	710	9,890	110
3	9,298		6,182	3,708
4	5,964	3,334	5,480	702
5	10,440		13,455	
6	10,450		13,074	381
7	4,545	5,905	7,226	5,848
8	16,429		15,655	
Total DEFE	76,416	9,949	80,962	10,749

Applying a Harvest Floor

Simulations to evaluate use of a first cutting period constraint (a harvest floor) were run for four of the models. These constraints require that first-period harvest be at least as great as first-period harvest in the previous planning iteration for each of the eight iterations. The models to which a harvest floor was applied are:

1. The base model (table 7).
2. The model with spatial dispersion constraints (table 8).
3. The modified land base model (table 9).
4. The more realistic forest planning model with both spatial dispersion constraints and modified land base (table 10).

For ease of comparison, the simulation results when no floor is imposed are also repeated in the tables showing simulation results. The analysis demonstrates the cost for each of the models tested of satisfying the intent of both the Multiple-Use Sustained-Yield Act (P.L. 86–517) and the NFMA which direct that national forests provide a nondeclining flow of wood products to society over time (i.e., the cost of eliminating any possibility of a DEFE).

The cost of imposing the harvest floor as measured by the present value of actions taken in the first eight planning iterations was quite modest in all of these models. The low magnitude of this cost can be explained by the financial characteristics of analysis area 5 which could never be harvested profitably. However, it did not have a large negative value when it was finally harvested because, after 50 years of stumpage value increases, the net harvest value per acre in decades 6, 7, and 8 was a loss of only $282. The relative magnitude of the present value loss for the solutions presented can be further explained by the fact that many of the occurrences of the DEFE seen in the earlier simulations, and that are prevented by the harvest floor, happen during later planning iterations.

Table 7 shows that applying a harvest floor to the base model results in a loss of present net value of only 1.11%. However, the revenue figures by planning iteration clearly show the problem that McQuillan emphasizes. In order to maintain harvest levels in planning iteration 7, the only available timber is in the unprofitable analysis area (AA5). This results in a negative cash flow of $188,000 for planning iteration 7, a situation that may be unacceptable. In general, such large decreases in revenue over time could be disruptive to the Forest Service.

Table 8 presents analogous information for the spatial dispersion analysis. The proportionate loss in present value associated with application of the timber harvest floor is 0.33%, or less than one-third of the loss present in the base model. The revenue flows in these simulations are much more uniform from iteration to iteration than are those in the base model. Although 172 acres of analysis area 5 are harvested at a loss in each of iterations 6 and 7, the spatial dispersion constraints

Table 6.—First-period comparison of the base model with the more realistic forest planning model used by the Forest Service (volumes are mbf).

Planning iteration	Forest planning model			FORPLAN base model		
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]	DEFE
1	3,750	0.574		10,000	1.532	
2	6,592	1.010		9,290	1.389	710
3	6,593	0.924		9,298	1.351	
4	6,600	0.968		5,964	0.736	3,334
5	7,500	0.872		10,440	1.840	
6	14,740	4.942		10,450	1.058	
7	14,528	4.614	212	4,545	0.460	5,905
8	10,780	3.435	3,748	16,429	7.575	
Totals	71,083	19.207	3,960	76,416	15.941	9,949
Revenue present net value		2.887			3.597	

[1]*Revenue is net first-decade revenue reported in millions of dollars.*

Table 7.—First-period comparison with a harvest floor applied (volumes are mbf).

Planning iteration	Without harvest floor			With harvest floor	
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]
1	10,000	1.532		10,000	1.532
2	9,290	1.389	710	10,000	1.450
3	9,298	1.351		10,000	1.453
4	5,964	0.736	3,334	10,000	0.949
5	10,440	1.840		10,000	1.162
6	10,450	1.058		10,000	1.012
7	4,545	0.460	5,905	10,000[2]	−0.188
8	16,429	7.575		16,667	7.687
Totals	76,416	15.941	9,949	86,667	15.057
Revenue present net value[3]		3.597			3.557

[1]*Revenue is net first-decade revenue reported in millions of dollars.*
[2]*667 acres of analysis area 5 are harvested at a loss.*
[3]*Reduction in discounted revenue over first eight planning iterations resulting from harvest floor = 1.11%.*

Table 8.—First-period comparison with spatial dispersion constraints with the same model with a harvest floor applied (volumes are mbf).

Planning iteration	Without harvest floor			With harvest floor	
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]
1	6,068	0.651		6,068	0.651
2	7,500	1.088		7,500	1.088
3	7,500	1.540		7,500	1.540
4	10,080	2.169		10,088	2.169
5	10,080	1.636		10,080	1.636
6	7,500	1.209	2,580	10,080[2]	1.160
7	7,500	1.209		10,080[2]	1.160
8	13,875	4.584		13,875	4.584
Totals	70,111	14.086	2,580	75,271	13.988
Revenue present net value[3]		3.023			3.013

[1]*Revenue is net first-decade revenue reported in millions of dollars.*
[2]*172 acres of analysis area 5 are harvested at a loss in each of these planning iterations.*
[3]*Reduction in discounted revenue over first eight planning iterations resulting from harvest floor = 0.33%.*

Table 9.—First-period comparison of the modified land base model with the same model with a harvest floor applied (volumes are mbf).

Planning iteration	Without harvest floor			With harvest floor	
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]
1	6,000	0.919		6,000	0.919
2	4,778	0.767	1,222	6,000	0.870
3	7,215	1.048		6,000	0.872
4	7,222	0.685		7,222	0.685
5	14,259	1.736		14,250	1.736
6	14,895	4.507		14,250	4.443
7	13,728	4.390	1,175	14,250	4.442
8	13,720	4.988		14,250[2]	4.532
Totals	81,817	19.040	2,397	82,222	18.499
Revenue present net value[3]		3.173			3.136

[1]*Revenue is net first-decade revenue reported in millions of dollars.*
[2]*285 acres of analysis area 5 are harvested at a loss.*
[3]*Reduction in discounted revenue over first eight planning iterations resulting from harvest floor = 1.17%.*

Table 10.—First-period comparison of the more realistic forest planning model with the same model with a harvest floor applied (volumes are mbf).

Planning iteration	Without harvest floor			With harvest floor	
	Harvest	Revenue[1]	DEFE	Harvest	Revenue[1]
1	3,750	0.574		3,750	0.574
2	6,592	1.010		6,592	1.010
3	6,593	0.924		6,593	0.924
4	6,600	0.968		6,600	0.968
5	7,500	0.872		7,500	0.872
6	14,740	4.942		14,740	4.942
7	14,528	4.614	212	14,740	4.610
8	10,780	3.435	3,748	14,740[2]	3.410
Totals	71,083	19.207	3,960	75,255	17.310
Revenue present net value[3]		2.887			2.886

[1]*Revenue is net first-decade revenue reported in millions of dollars.*
[2]*250 acres of analysis area 5 are harvested at a loss.*
[3]*Reduction in discounted revenue over first eight planning iterations resulting from harvest floor = 0.03%.*

conserve enough valuable timber and limit the harvest of stands that cannot show a profit to levels that still provide significant ($1.16 million) revenue in these planning iterations.

Table 9 presents analogous information for the modified land base simulations. The proportionate loss in present value associated with application of the harvest floor is the largest of the four models examined. The reason the loss is so large relates to the early timing of the largest expression of the DEFE. Initially there is a reduced amount of highly profitable timber; consequently, a departure of 1,222 mbf occurs in planning iteration 2. The effect of the floor increases the harvest so much above optimal levels early in the process that the effects of discounting cause a relatively large impact on the revenue present value. However, the sequence of cash flows did not display the dramatic decreases shown in tables 7 and 8.

Table 10 provides analogous information for the more realistic forest planning model simulations. The proportionate reduction in present value resulting from application of the harvest floor was quite small, being only 0.03% as compared with a reduction of 1.11% in the base model. In addition, the revenue was fairly stable over time in the sense that large proportionate decreases were not observed.

Two inferences can be made from the results of the harvest floor simulations. First, even when the harvest floor is applied, the nature of the constraints in Forest Service models insures that first period revenues will to be more uniform than is the case in the unconstrained model portrayed by McQuillan (tables 8–10 vs. 7). Second, these constraints also result in a significant reduction in the cost of the harvest floor in the simulation most representative of Forest Service planning models (table 10 vs. 7).

SUMMARY AND CONCLUSIONS

The case study developed in this report clarifies sever- aspects of the DEFE. Although the DEFE can and will cur in future national forest plan updates, its expect- magnitude can be significantly reduced by the charac- istics of the Forest Service planning process. Three ctors were found to have a large impact in nearly all est planning models:

1. Spatial and temporal dispersion constraints tend to apportion harvest from an analysis area over several cutting periods, rather than allowing immediate complete exploitation.
2. The initial timber age class distribution typically includes many stands regenerated before the start of the planning process. These become available for harvest in the decades between early harvest of profitable old-growth stands and eventual harvest of stands regenerated during the first or later iterations of planning.
3. Many forest plans assume increasing product prices in the early part of the planning horizon. This allows additional analysis areas to become profitable during the early decades of the planning horizon, helping to bridge the potential harvest gap between profitable old-growth liquidation and harvest of regenerated stands.

In addition, the average forest planning model is very ghly constrained in order to address local issues, and any of these constraints may also interact to inhibit the EFE. Because of the local nature of these issues, their pact was not (and could not be in general) evaluated this study.

One factor we expected would reduce the DEFE may t, in general, do so. FORPLAN models often select any prescriptions that involve thinning harvests. In ad- tion, these thinnings are often concentrated in the cut- g periods between liquidation of the old growth and e final harvest of regenerated stands. Thus, it seems ausible that the use of profitable thinnings can bridge e gap between old-growth liquidation and terminal rvest of regenerated stands. The case study developed ove shows that extensive use can be made of profita- e intermediate harvests without significantly reducing e DEFE.

The case study demonstrates the relationship between rtain aspects of the planning process used by the Forest rvice and the DEFE. This increased understanding can used to identify forests at high risk of severe DEFE. e potential problem should be recognized and ad- essed in the planning process.

FORPLAN formulations that directly address the op- n of departures are needed. The current approach in rest planning is to allow limited increases or decreases planned periodic harvest levels. Figure 1 shows ex- iples of this type of alternative (alternatives M and N) the Kootenai National Forest. However, these "limit- d departures" are often not viable options. In the ab- nce of other constraints, and with a predominantly d-growth forest, the harvest scheduling model would select a high initial harvest level followed by a series of harvest reductions in later cutting periods. This sequence of harvest levels would allow much faster liquidation of the old-growth, but at the cost of repeated departures. The repeated departures would be very hard to justify in practice.

A more appropriate analysis could be developed by future research to address the question of planned departures. There are several desirable characteristics for a more robust analysis of departures. First, the analysis should address the option of allowing future departures within the current iteration of planning. Second, the approach should allow specification of the maximum number of departures that would be acceptable. In practice, this number would be quite small (one or two), rather than the repeated harvest reductions resulting from the current "limited departures" analysis. Third, the timing of the departures should be optimally scheduled. And, fourth, the analysis should allow the maximum magnitude of each departure to be specified.

A much more complete and appropriate analysis of the question of future departures would be possible if a FORPLAN option with these characteristics were available. Analysis using this tool could directly address the DEFE. In addition, other vexing issues of the forest planning process, such as the allowable cut effect and estimating the opportunity cost of the nondeclining yield constraints, could be addressed.

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The declining even flow effect (DEFE) identified by McQuillan (1986) may be a serious flaw in the planning process used by the USDA Forest Service. This report addresses the relationship between this process as it is used to develop FORPLAN models and the DEFE. A case study is used to show that certain items common to all FORPLAN models reduce the magnitude and number of occurrences of the DEFE.

Keywords: Timber harvest scheduling, linear programming

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station


Rocky Mountains


Southwest


Great Plains

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United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-187**

Climate Change and America's Forests

Linda A. Joyce, Michael A. Fosberg, and Joan M. Comanor

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93–378, 88 Stat. 476, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each tenth year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 13 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1976, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Forest Service analysts prepared a number of assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

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Climate Change and America's Forests

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Contents

Climate Change and America's Forests

Linda A. Joyce, Michael A. Fosberg, and Joan M. Comanor

Introduction

The timber projections in the Forest Service Assessment assume a future in which the climate follows historical trends and in which changes in timber production and land use are an outgrowth of these trends, not abrupt discontinuities from the past (Darr in press, Haynes in press). These assumptions may not be met if the earth's climate changes rapidly.

Since the beginning of the industrial revolution, the chemistry of the atmosphere has been altered by increases in the concentrations of trace gases such as carbon dioxide and methane. These greenhouse gases trap a portion of the earth's infrared radiation and warm the planet. Further increases in the concentration of these greenhouse gases are predicted to raise the atmospheric temperature by 3 to 5°C within the next 100 years—a time span comparable to the planting-to-harvest interval of many commercial tree species. Major changes in the location and abundance of North American tree species were associated with a similar 5°C warming that occurred over a period of 8,000 years between 15,000 and 7,000 years ago (Bernabo and Webb 1977). This interglacial temperature change is of the same magnitude as the predicted temperature rise, 5°C, but this currently predicted temperature rise is projected to occur in less than 100 years, one one-hundredth of the interglacial time span.

Our perception of change is often associated with seasonal to decadal regional weather changes, such as the summer drought of 1988 or the hot, dry years in the 1980's; and local to regional environmental changes, such as the impacts of acid-rain or urban smog on vegetation. As we begin to understand the earth system, we need to consider long-term changes, such as those changes associated with global climate. There is great uncertainty in the projections of climate change on local ecosystem responses. However, we can say that these factors will play a major role in abrupt changes in the landscape: changes in precipitation and, to a lesser extent, temperature will restrict the persistence of ecological systems; and changes in disturbances, such as fire, insects, and disease, will impose new and different stresses on ecosystems. There is great need to determine the impact of this potential climate change on North American ecosystems and, in particular, our forest resources. Reliable estimates of the magnitude and rate of climate change are needed at many decision levels within society: individuals (e.g., ranchers and farmers), industry (e.g., forestry), and governments (e.g., resource managers and regulators). This document summarizes the current research on the impacts of climate change on America's forests.

The Greenhouse Effect

Scientific Bases for the Greenhouse Effect

The balance between the incoming solar energy and the outgoing energy determines the earth's temperature. A small change in either direction would result in a cooling or warming of the earth. Approximately 43% of the incoming energy is absorbed at the earth surface and this energy warms the land and oceans. A portion of the received energy warms the atmosphere directly through heat transfer. A portion is also reradiated toward space as long-wave infrared radiation. A small percentage of this outgoing long-wave radiation is absorbed by certain trace gases such as carbon dioxide, methane, and water vapor, and this absorption further warms the atmosphere. If the total incoming solar energy is balanced by the total energy returned to space, the temperature of the earth would remain constant. The equilibrium temperature for the earth is currently 15°C.

Recent interest in the greenhouse effect is focused on whether the equilibrium temperature has been disturbed through increases of the greenhouse gases such as carbon dioxide, methane, nitrous oxides, and others (Hansen et al. 1987). Precise monitoring of the amount of carbon dioxide in the atmosphere (Keeling 1984) has shown a steady increase since 1958, the beginning of the record at Mauna Loa Observatory (fig. 1). Comparing these recent data from direct methods with measurements of atmospheric carbon dioxide from indirect methods, such as carbon dioxide in air trapped in permanent ice fields and the analysis of isotopic carbon ratios in tree rings, indicates that before 1850, atmospheric concentration of carbon dioxide was approximately 270 ± 10 parts per million (ppm), as compared to the current level of 350 ppm (Hoffman and Wells 1987). This 25% increase in atmospheric carbon dioxide since 1850 is important because atmospheric concentrations of carbon dioxide are strongly correlated with global temperature. Ice core data extending back 160,000 years (fig. 2) clearly demonstrate this correlation (Fifield 1988, Friedli et al. 1986). Increases in other greenhouse gases such as methane have also been observed (Hoffman and Wells 1987). The increases in atmospheric carbon dioxide are attributable to human activities such as the burning of fossil fuels, deforestation, the burning of forests, byproducts from agriculture such as methane from cattle and rice production, and release of manufactured chemicals such as chlorofluorocarbons, and biotic sources such as the decomposition in forests and carbon cycling in oceans.

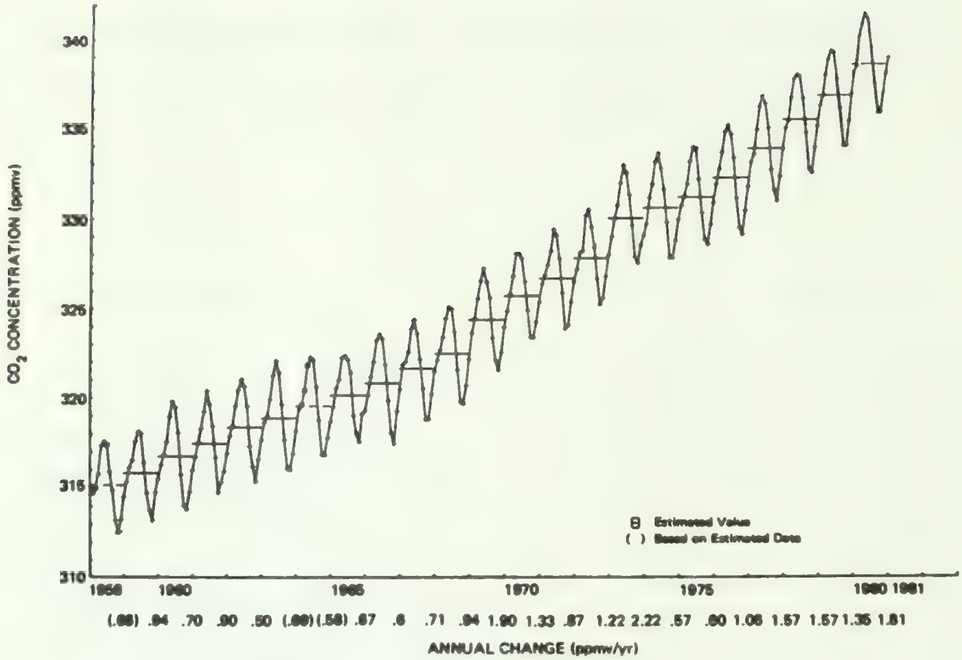


Figure 1.—Mean monthly concentrations of atmospheric CO_2 at Mauna Loa. The yearly oscillation is explained mainly by the annual cycle of photosynthesis and respiration of plants in the northern hemisphere (after National Research Council 1983).

Projections of future concentrations of these greenhouse gases are based on forecasts of energy consumption, energy efficiency, and population growth. Current projections indicate that with present technology and population growth, the concentrations of the greenhouse gases would double by the year 2030, and that even with high levels of energy conservation and efficiency, concentrations would double by 2075 (Mintzer 1987).

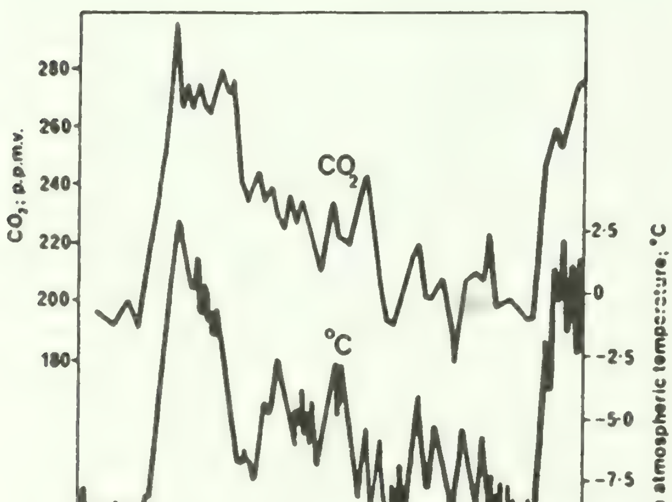


Figure 2.—The Vostock record of temperature from Antarctica, and concentrations of carbon dioxide in the atmosphere (from Fifield 1988).

Quantifying the Atmospheric and Ecological Responses

Modeling the Atmospheric Response

General circulation models (GCM's) are the equations representing the physical concepts of conservation of mass, energy, and momentum. Such models describe the atmosphere and oceans with a large number of discrete points for which forecasts of temperature, pressure, water (for the atmosphere), and salinity (for the oceans) are made. These forecasts permit calculation of clouds, wind, precipitation, and exchange of energy between the biosphere and the geosphere (Dickenson 1982, Schneider 1988).

Major weaknesses and sources of uncertainty in applying these models to predict future ecosystem responses are: (1) coarse spatial resolution, (2) inadequate representation of the role of clouds in the energy balance, and (3) inconsistent prediction of the hydrologic cycle. Spatial resolution of these models is very coarse, 5–7 degrees of latitude and longitude, when compared to ecosystem dimensions. Physical processes associated with small physical dimension phenomenon such as individual clouds cannot be described in these models. Instead, such processes are represented by an expected mean effect on the energy, mass, and momentum budgets. This shortcoming is particularly acute in mountainous regions where ecosystem dimensions are very small and are strongly related to elevation, and where local climate variations are large (Schlesinger 1988).

Representation of clouds in these GCM's is particularly important because of their influence on both incoming solar radiation and outgoing infrared radiation. Intercomparison of the different GCM predictions have attempt-

ed to reduce the uncertainty resulting from how clouds influence the model results (Schlesinger 1988), but there s still need for improvement before this problem can be considered resolved (Cess et al. 1989). Effects of clouds on the local energy exchange is three times that predicted from the greenhouse gases (Ramanathan et al. 1989).

How the oceans are depicted affects the prediction of hydrological cycles. In some GCM models, oceans are epresented by a shallow ocean in which predetermined ea surface temperatures are used to regulate the atmospheric circulation. In other models, a deep ocean with ocean current to redistribute the heat is used, but hese models do not show consistent results (Bryan 1988, Schlesinger 1988).

The four models, Oregon State University (OSU), National Center for Atmospheric Research (NCAR), NASA Goddard Institute for Space Studies (GISS), and the Geophysical Fluid Dynamics Laboratory (GFDL), show a degree of consistency in predicting the future temperature rise and the regional distribution of these temperatures. Also, all four models predict that the global precipitation will increase, primarily because a warmer atmosphere has a higher saturation vapor pressure (Mitchell 1988). Intercomparison of model results for egional precipitation distribution shows far less consistency (Kellogg and Zhao 1988). This lack of consistency is particularly troublesome because the hydrological budget is more important than temperature in determining leaf area, vegetation structure, and the mass of vegetation (Woodward 1987).

The rate at which climate will change is important. If he climate evolves slowly, the biosphere may be able to adapt. Three of these models attempt only to predict the equilibrium climate of the future. Only the GISS model allows the greenhouse gases to increase with time and gives an estimate of the rate of climate change.

Coupling the Biosphere to the Geosphere

Direct, interactive coupling of the biosphere to the atmosphere in global models so that there is a direct exchange of mass and energy (Abramopoulos et al. 1988) will need to be improved dramatically before results useful to resource managers will be available. Current approaches only attempt to describe the heat and water vapor exchange and make little reference to the structure and composition of the ecosystem, to the abundance of individual species, or to any mediating effects of the biosphere on the atmosphere. Heterogeneity of land and water distribution on the surface of the earth contribute to the difficulty of interpreting mean values for climate over a varied region.

Modeling the Ecological Response

Without models that directly link atmospheric processes to ecological processes, climate projections from GCM's are used to construct scenarios as a context in which to examine the behavior of extant ecological models. Attempts to quantify the role of terrestrial biota in the global carbon cycle have their origins in global models of carbon flux (Houghton et al. 1983). Such models have been used to estimate where carbon is stored globally: 617 10^9 tons in vegetation and 1,652 10^9 tons in soils of terrestrial ecosystems (Woodwell 1983), 39,660 10^9 tons in oceans, and 740 10^9 tons in the atmosphere. In addition, these models have been used to estimate the net biotic flux of carbon (carbon release to the atmosphere from deforestation and other changes in land use) which, in 1980, was estimated to be 1.9 $\pm$ 0.99 10^9 tons carbon with only 0.11 10^9 tons carbon released from outside the tropics (Houghton et al. 1987). Models of this type quantify the biotic contribution to atmospheric carbon dioxide and must be compared to models computing the nonbiotic contribution of human activities to atmospheric carbon dioxide (Nordhaus and Yohe 1983). World consumption of fossil fuels contributes nearly 5 10^9 tons ($\pm$10%) per year to the atmosphere with the United States contributing about one-fourth of this emission (Carbon Dioxide Assessment Committee 1983).

Current approaches to modeling the ecological response to climatic change differ by the questions they attempt to answer: physiologically-based plant models, population models, ecosystem models, and regional or global models (Agren et al. in prep.). The response of individual plant processes to climate change is the focus of physiologically-based models. While such models contribute to our understanding of biochemical reactions within plants, these models lack mechanisms to examine interactions of nutrient cycling or species competition at a scale larger than a single plant.

Plant establishment, growth, seed production, and death are simulated in population-community models. Gap-phase models, one example of population-community models, offer a way of predicting future forest species composition under disturbance at a scale that is meaningful to resource managers. These models predict the establishment, growth, and death of individual trees and implicitly account for competition for light, water, and nutrients among trees (Botkin et al. 1972). Such models allow individual species to die and to be replaced by new species that are better adapted to the environment, or that are more competitive for light, water, and nutrients. A major uncertainty in these models is the rate of species dispersal into a region and the lack of explicit dispersal mechanisms (U.S. EPA 1988). In the current models, a species is present or absent, and when present, migrates at the same rate as climate change—an unlikely assumption.

Ecosystem models focus on the biogeochemical processes of fixation, allocation, and decomposition of carbon, and the cycles of nitrogen, phosphorus, sulfur, and other elements. Rates of nutrient cycling may change more rapidly than species composition (days to years versus years to centuries) and, thus, change the environment for species interactions. It is unclear how much climate-induced process-level change (e.g., decomposition) occurs within ecosystems before plant community turnover occurs and, conversely, to what extent species changes drive process-level changes in these systems (Davis 1988). Incorporation of nutrient cycling in gap-phase models in forests (Pastor and Post 1988) suggests that a synthesis

of these two approaches will be needed to unravel the likely changes in species abundance and ecosystem processes (Davis 1988).

Recent regional and global models use the coincidence of climate and vegetation zones (correlation) to describe the future distribution of plant communities. The Holdridge Life Zone Classification system (Holdridge 1964) is based on correlating vegetation type (e.g., spruce-fir) to gradients of temperature, precipitation, and the ratio of potential evapotranspiration to precipitation. Historical pollen records can also be correlated with records of past climate, and these correlations can be used to predict future vegetation distributions under a projected climate. All of these approaches are based on the equilibrium relationship between climate and vegetation distribution and can be helpful in determining the global distributions of vegetation under steady state. The assumption of steady state implies that under climate change, the vegetation at a site shifts to the plant community for which the new environmental condition is the optimal climate. If climate zones were displaced geographically, the forest, as it looks now, would migrate with its preferred climate. Such migration may be possible if climate were to change slowly, but under rapid climate change, maintaining an intact forest would be difficult or even impossible because each species in the forest will migrate at a different rate (Davis 1981). This disassociation of species in migrating forests was clearly observed during the early Holocene (Bernabo and Webb 1977).

The major shortcoming of all current approaches is the omission of disturbances such as fire, insects, disease, and pollutants. These analyses do not address potential changes in the frequency and severity of traumatic events and how such changes, in turn, will impact primary productivity, seed production, seedling establishment, and species competition. Insects and animals, particularly herbivores, represent a disturbance that could significantly change species composition as well as nutrient cycling processes of ecosystems under climate change. For example, if hardwoods replace conifers, gypsy moth defoliation will certainly influence primary productivity unless mitigating action is taken (Wingert 1988). Also, if cottonwood (*Populus deltoides*) becomes a more important species for pulp and paper, impact of climate change on melampsora leaf rust (McCracken et al. 1984) must be taken into account (Fosberg 1988).

Increased insect- and disease-caused losses in our nation's forests will become one of the first observed effects of climate change. Evidence can be found in the pest-caused epidemics which now occur as a result of periodic droughts or rainy periods. Changes in climate either through effects on the pest or on the host may increase or decrease pest-caused losses. High temperatures and reduced precipitation cause insect epidemics when these climatic factors stress the tree (host) to the point that the hosts lose their inherent resistance to native pests. Increased moisture can increase losses where disease was limited in distribution and infection was limited by low moisture conditions. Under climate change, currently important pest problems may all but disappear and new epidemics will arise. These pest attacks will often determine the new geographic distribution of tree species under th new climatic conditions.

Fire frequency and severity is also missing in assess ing the impact of climate change on forests. Charcoal ana lyses of sea sediments (Herring 1985) have shown a wea but definite trend of charcoal deposition over the last 5 million years. Charcoal analyses of lake sediments hav shown fire cycles and climatically induced changes i fire regimes (Clark 1988). Combining these data with tem perature relations (Fifield 1988), we see a weak but posi tive correlation between temperature and charcoal suggesting increased fire frequency under warme climates.

There are few definitive studies of the direct effects o climate change on fire frequency and severity. Direct ef fects would be the changes in drought frequency, humid ity, precipitation, and other weather elements tha determine day-to-day variation and interannual variabil ity in fire behavior. Fried and Torn (in prep.) compare the changes in area burned under the current and a double carbon dioxide climate. They found that ther would be a two-fold increase in modest-sized fires (a fev hundred hectares) and a three-fold increase in fires great er than 1,000 hectares. Fried and Torn (1988) based thei studies on an area of the California Sierra Nevada i which the ecosystems are expected to remain unchange in a future climate.

For many regions, species composition of forests is projected to change. Much of the structure and compo sition of a forest will remain long after climate change induced stress has prevented regeneration of those spe cies. New species will take hold during the transitio from one vegetation community to another, and a tran sitional forest will contain elements of both vegetatio types. As the structure, composition, and total biomass of the forest change, so will the behavior of fire. A shif on the uplands to hardwood savannahs will likely cause an increase in fire severity in the Lake States (Fosberg 1989).

The size, shape, and distribution of forest land, forest types, and successional stages create a mosaic across the landscape that contributes to the production of wildlife and the use of land for other resources such as grazing. There is concern that the current increasing forest fragmentation will eliminate some species as functioning members of certain regional faunal communities (Flather and Hoekstra 1989). The spatial pattern of land use and vegetation cover influences the migration and dispersal of insects, birds, and animals, and these influences under a changing climate remain to be considered in ecological models. The impacts of changing forest type and the associated changing interspersion on wildlife and other resources have not been addressed.

Forest Changes Under Climate Change

Assessment of the forest resources 50 to 100 years from now as a result of the greenhouse effect has not been done in any systematic fashion. Coverage of the country is not uniform, several estimates were made for some regions

nd only one estimate for others, and, finally, different nethods have been used for different regions. While esearch is in process on modeling the ecological re-ponse to climate change, several existing models have een used to examine GCM scenarios. Gap-phase models iave been used to examine changing species distribu-ions in eastern and western forests. Other approaches iave included interpreting historical change as an indi-ation of future change. Correlation of modern pollen dis-ribution with climatic data gives a model that can be ompared to fossil pollen records under different cli-nates and used to project species distribution into fu-ure climates (Overpeck and Bartlein 1988, as described n U.S. EPA 1988).

These ecological models use climate scenarios from he GCM's as inputs in order to quantify the ecological esponse. Interpretation of these results must consider he uncertainties of GCM climate projections, the poten-ial interactions for disturbances and interactions not cur-ently in the ecological models, and, finally, the ncertainties in the ecological models themselves. In hose regions where more than one model or method has een applied, coincidence of prediction may give more upport to estimates.

astern Forests

Most projections indicate a movement of conifers north vith an inward migration of hardwoods from the South, movement of grassland and savanna types eastward on he western boundary; however, the degree and magni-ude of these changes vary. In the New England states un-ler a more severe GFDL-correlation projection, conifers spruce, northern pines) would retreat into Maine; iowever, there would not be appreciable change under milder GISS-correlation scenario (U.S. EPA 1988). Us-ng these same two models, sugar maple shows a simi-ar pattern (U.S. EPA 1988). Using gap models, the New ngland forests would be replaced by more hardwoods, articularly by oak species from the eastern mid-United tates (Botkin et al. 1988; Overpeck and Bartlein 1988; abinski and Davis 1988, as described in U.S. EPA 1988).

For the Great Lakes area (U.S. EPA 1988), conifers spruce) will likely remain in the northern portion of the reat Lakes region and potentially migrate as far north s James Bay with a GISS-correlation scenario. Under a FDL-correlation scenario, conifers (balsam fir) would e totally lost from the Great Lakes region. Sugar maple vould show similar migration patterns under these two cenarios. The gap-phase model simulations show less ramatic changes. Under a GISS-gap-phase model cenario, Botkin et al. (1988) predicted that the boreal rests would disappear by 2040 from the northern Lake tates region and that sugar maple, oaks, and other hard-voods would dominate on the drier and better sites in iis area, with the potential for increased biomass. On iore southerly maple-oak sites, tree biomass would ecline 37% to 99%. Solomon and West (1987), using the ICAR GCM, also show hardwoods preferred over onifers, but conifers remained in the region. This simu-ition predicted a decrease in biomass. Using correlation

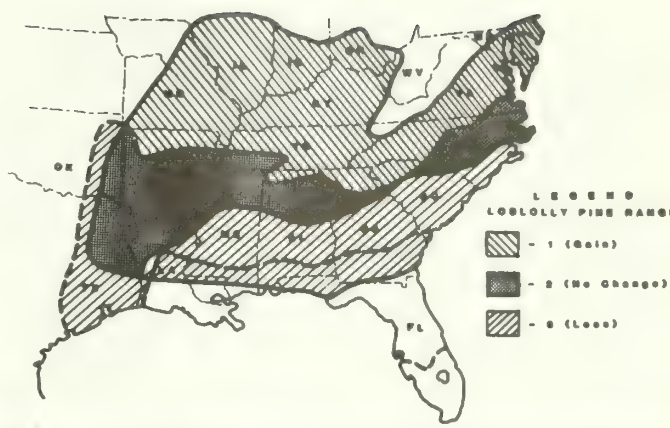


Figure 3.—Projected changes in loblolly range assuming doubled atmospheric CO_2 (after Solomon et al. 1984)

analysis, Zabinski and Davis (as cited in U.S. EPA 1988) predicted local extinction of tree species such as eastern hemlock and sugar maple in the Great Lakes region. Southern pine species could migrate into the present hardwood forest lands of eastern Pennsylvania and New Jersey (U.S. EPA 1988).

South and Southeast

Most projections indicated a decline of southern forests as we know them, a reduction in the biomass, conversion of some forests to grassland, species regeneration becoming difficult, and a movement of southern pine species north. Using a gap-phase model and GFDL, GISS, and OSU climate scenarios, southern pines would be greatly reduced or eliminated in Mississippi, South Carolina, and Georgia (Urban and Shugart 1988, as cited in U.S. EPA 1988). Biomass would be reduced 30% in Tennessee. An earlier analysis by Solomon et al. (1984) also predicted a marked reduction in Mississippi, Georgia, and South Carolina, and showed loblolly pine invading into Tennessee (fig. 3). Under GFDL-correlation and OSU-correlation scenarios, southern pines extended northward but did not move out of the South and Southeast (Winjum and Neilson 1988).

Miller et al. (1987) described the subtle implications of these projections. The current distribution of loblolly pine is overlain on relatively deep soils, whereas areas into which loblolly is projected to move have a relatively high proportion of shallow, steeply sloping, coarse-textured soils on rocky uplands. Thus, even though the area of the range has increased, productivity is likely to decline because of the marginal productivity of these sites. The seasonal distribution of precipitation and temperature under climate change could also affect the quality of wood for loblolly. An extended period of drought in the northern limits of its range would result in lower-specific-gravity wood and, thus, wood of poorer quality.

West

Projections for the West focused on correlation analysis and, consequently, focused on individual species responses rather than community-level projections. Spe-

cies responses indicated either movement up an elevational gradient or northward migration. Leverenz and Lev (1987), using correlation and an unspecified GCM, predicted that Douglas-fir (fig. 4) would expand to higher elevations as the lower limit of the continuous winter snowpack climbs upslope. Increased summer drought and rising winter temperatures result in declining importance of Douglas-fir on the east slope of the Rocky Mountains and in the southern limit of its current range.

The range of ponderosa pine (fig. 5) in interior Washington and the eastern slope of the Rocky Mountains would decrease with deficit spring water balances (Leverenz and Lev 1987). While summer drought allows ponderosa pine to expand in California and Oregon, increased temperatures are projected to push ponderosa pine upslope in these states and in Washington, Montana, Idaho, and the middle and southern Rocky Mountains. The southern Rocky Mountains would have major losses in ponderosa pine (fig. 5).

Western hemlock would be restricted to the wetter sites west of the Cascade Mountains. In the northern Rocky Mountains, western hemlock and western larch would be lost in the Idaho panhandle and eastside of Oregon and Washington (Leverenz and Lev 1987). Lodgepole pine would not be effected greatly in its western extent. No estimates were made for redwood or other species.

Western larch was projected to increase on better sites and on sites where fire frequency is increased. On site where summer drought increases, western larch will b restricted to upslope movement.

Sensitivity of Forest Species Predictions to Uncertainties in the General Circulation Models (GCM's)

The four GCM's predict that the global mean surface temperature rise will range from 2.8°C to 4.2°C (Schlesinger 1988). North American regional and seasonal distributions of these temperature increases differ by as much as 8°C for summer and by 4°C for winter (Schlesinger 1988). Not only does the projected global mean vary, but the implication to regional climate patterns varies by model. When the spatial and seasonal distribution of precipitation is expressed as soil moisture the southwestern, southern, and southeastern states are expected to be drier during the winter (fig. 6). During the summer, the entire country is expected to be drier (Kellogg and Zhao 1988). However, there are marked differences between each of the model predictions in both winter (fig. 6) and in summer (fig. 7). Areas of greatest discrepancy and, therefore, uncertainty are in winter precipitation for the West Coast, the Great Basin,

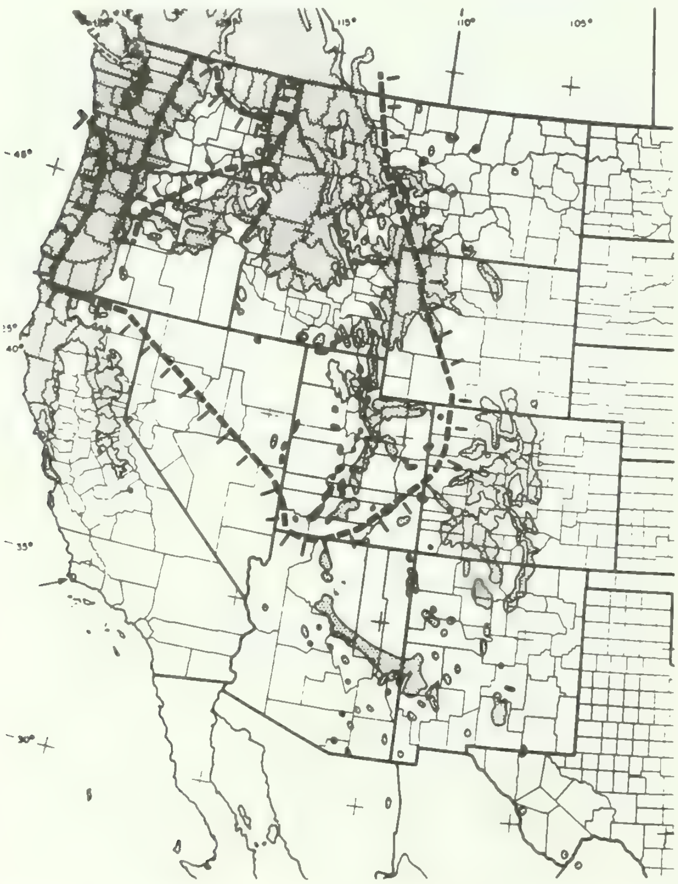


Figure 4.—The current distribution of Douglas-fir and projected distribution under a doubled CO_2 scenario. Hatching is directed toward the zones of decreasing acreages (after Leverenz and Lev 1987).

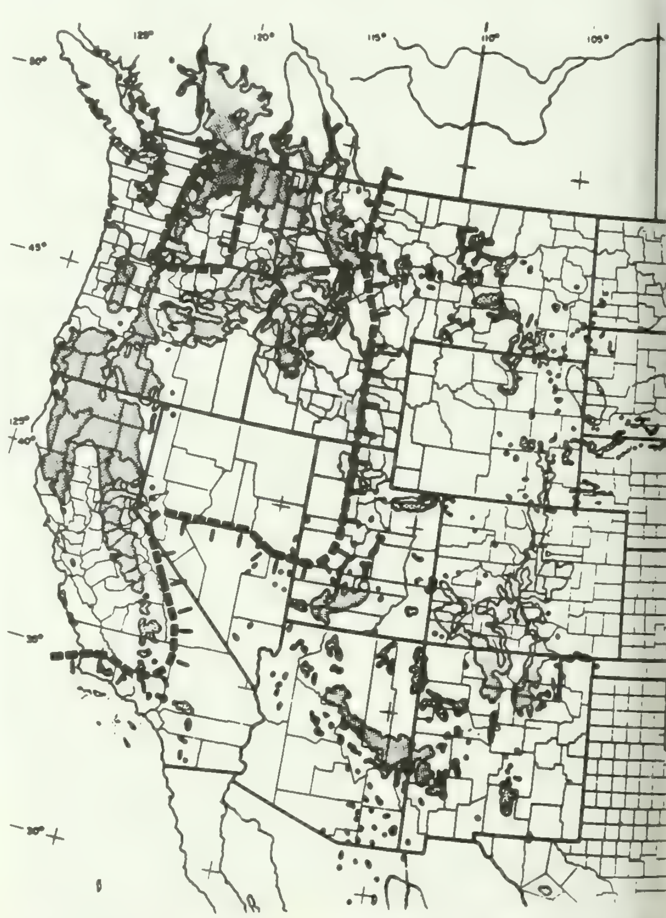
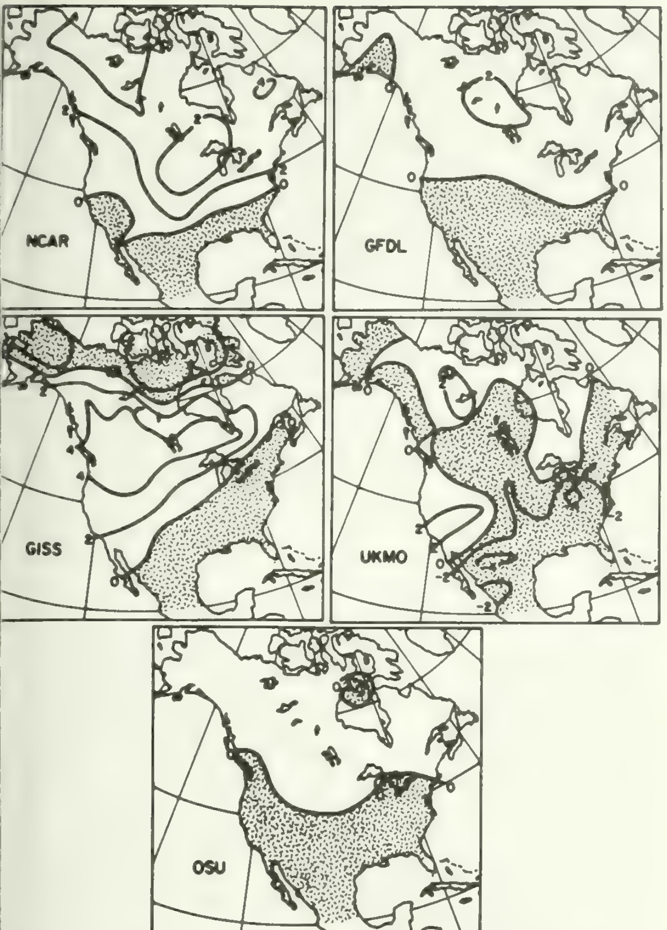


Figure 5.—Current distribution of ponderosa pine and projected distribution under a doubled CO_2 scenario. Hatching is directed toward the zones of decreasing acreages (after Leverenz and Lev 1987).



igure 6.—Increases (clear areas) and decreases (scratches) of winter soil moisture relative to the control when carbon dioxide is doubled (after Kellogg and Zhao 1988).

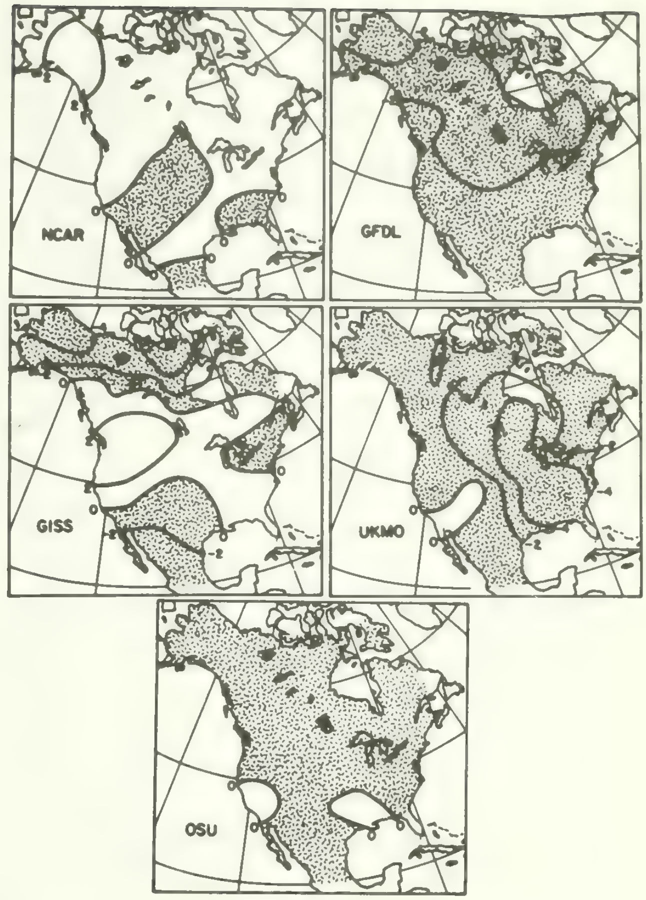


Figure 7.—Increases (clear areas) and decreases (scratches) of summer soil moisture relative to the control when carbon dioxide is doubled (after Kellogg and Zhao 1988).

ocky Mountains, the Mid-West, and the Northeast. here is greater consistency between the predictions and onfidence during the summer.

Natural variations in annual precipitation and mean emperatures have always existed. During the past 100 ears, the long-term temperature record for the United tates has not shown any systematic change, but has anged from 10.6°C to 12.8°C (Karl and Jones 1989). Over he last 2,700 years, which includes the Little Ice Age of he 17th century, North America has experienced a natural variability of 1.5°C (Bernabo 1981). Similarly, precipiation has shown large year-to-year variability during the ast 2,000 years (Stahle et al. 1988). The Palmer Drought ndex shows abnormally dry or wet periods are more ommon than normal precipitation during periods of hange (Stahle et al. 1988).

Given the uncertainty in the predictions, and the natural variability that climate change must exceed before we an detect effects, what can we say about impacts on the cosystem? Two independent analyses of climate change mpact have been completed for the Lake States. Both of hese studies used gap-phase models, and both were ased on GCM predictions of climate for a doubled caron dioxide concentration in the atmosphere. The differnce between these two predictions is that two different GCM's were used. Solomon and West (1987) used the NCAR model while Botkin et al. (1988) used the GISS model. These two analyses provide us with some measure of the simulated ecological sensitivities to climate change prediction. Differences between the two simulations are that, in one, conifers will be totally replaced by hardwoods and, in the other, conifers will be retained. Also, the two differ in the number of trees per hectare, one showing an increase and the other a decrease. Similarities are that both simulations show a decrease in total biomass. The comparison suggests that some confidence may be placed on prediction of total biomass, but less on the structure and abundance of individual species.

Ecological Uncertainties in the Projections of Climate Change

Current projections of the potential impacts of climate change have limitations because of the omission of some important processes controlling forest production, particularly in response to disturbance or stress. In addition, the physiological responses of individual plants to elevated carbon dioxide under moisture, temperature, or other nutrient limitations remain to be definitively described for natural settings. The fertilization response reported for some species to elevated carbon dioxide levels may

be a short-term or transient response, reflecting an adjustment to new and different levels of nutrient availability. As current forest growth is limited by water and/or nitrogen, the impact of climate change will involve not only elevated levels of carbon dioxide, but also changes in the seasonal distribution of precipitation and temperature, both poorly described variables at the regional scale in the current GCM's.

Changes in atmospheric temperature and precipitation will affect soil moisture and soil temperature, two environmental factors controlling the cycling of nutrients in the soil. The rate of nitrogen mineralization has been shown to be positively related to net primary productivity of trees and wood production (Nadelhoffer et al. 1985) (fig. 8). Potential increases in the carbon to nitrogen ratios in aboveground plant parts, such as leaves, would shift the carbon content in litter, resulting in lower quality litter. Declines in litter quality (less relative nitrogen) could decrease mineralization rates and, in turn, productivity of the stand could decline. In other areas, elevated soil temperature and moisture could enhance soil mineralization rates and improve stand productivity. Thus, shifts in the mineralization rates of nutrients could impact forest productivity.

Individual species migrate at different rates; thus, forest vegetation will begin to uncouple as we currently know it and species interactions, which do not currently occur, will begin to play a role in the development of future plant communities. The migration of understory species, important in early-successional stages of forest development and for grazing and browsing animals, could affect the future availability of forage. Potential increased levels of drought will not only reduce vegetation but provide open niches for invading species from nearby geographic regions. Changes in climate are projected

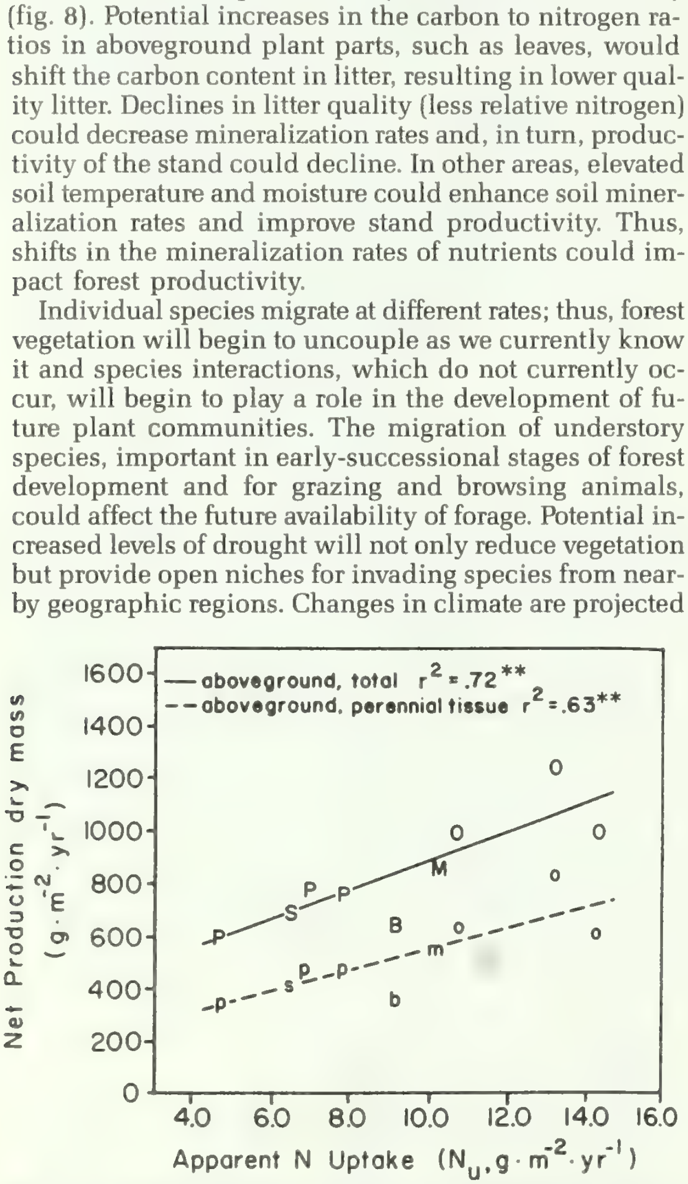


Figure 8.—Aboveground total net primary production (bole and branch plus leaf litter) and aboveground perennial tissue (bole and branch) in relation to annual nitrogen (N) uptake. Symbols designate dominant genera on sites: P = pine, S = spruce, B = birch, M = maple, O = oak. Upper and lower cases designate aboveground production and perennial tissue, respectively. Regression lines through data were significant at the P < 0.01 level (after Nadelhoffer et al. 1985).

to be greatest for the mid-latitudes with only a small increase (1°C) in temperature at the equator. Thus, species diversity in the most diverse plant communities, the tropics, will change less as a result of projected climate change than current land use. Species diversity in the polar and mid-latitudes will likely have the greatest changes. Potentially significant impacts could occur on rare species which are currently found only in refuges located on the basis of their current distribution.

Assessing the impact of resources dependent upon forest production is even more limited. Numerous species of plants and animals are confined to a coincidence of environmental parameters. If jack pine are replaced by hardwoods in northern Michigan (Botkin et al. 1988), the Kirtland's warbler could become extinct. Even though jack pine would fluorish north of the Great Lakes, there is a lack of sandy soil north of the Great Lakes and the Kirtland's warbler nests on sandy soil under jack pine. Similar situations could arise in mountainous areas for other species (Peters 1987). For many reptiles, sex of an individual is determined from temperatures during the egg incubation period. Thus, climate change will affect not only the habitat of the animals but also the energetics and reproduction of their populations. Examples exist where changes in the landscape facilitated an expansion of species previously occupying only a small part of the system. The greatest extent of the Kirtland's warbler occurred after the fire frequency changed dramatically in northern Michigan following settlement in the early 1900's (Whitney 1989). These examples reflect our current understanding of the complicated interactions between plants, animals, and environment in the present ecosystems and suggest subtle interactions not easily determined for the future climates.

The spatial distribution of vegetation across the landscape influences the abundance of wildlife and fish as well as the use of that land for agricultural and forestry purposes. It is difficult to determine changes at the landscape level resulting from climate change and what these changes will imply for land use. A very high percentage of domestic and agricultural water comes from public lands, particularly in the mountainous West. Increased temperatures could be expected to cause early and more rapid snow melt (King et al. 1988). Increased disturbances such as fire will impact the management of that forest and potentially impact water quality (U.S. EPA 1988). With changed seasonal precipitation, the ratios of springwood and late wood will vary from those of today, and frequency of insect and disease outbreaks and the severity of outbreaks will change. Insect- and disease-damaged wood is of lower quality (Becker 1987). The visual impact of forest declines, as well as changing forest species, will impact the recreational use of forest land. And finally, the socioeconomic impacts of changing forest species could include unemployment, community instability, industrial dislocation, and increased net imports of wood products. Changes in what people will expect from the forest will need to be addressed for future climates.

Research to address these questions is ongoing or has been proposed (Bartuska 1989; Committee on Earth

Sciences 1989; Fox and Krebill 1989; Sandberg and Bell 1989; Special Committee for the IGBP 1988; USDA Forest Service 1988a, 1988b). Generally, the main elements of hese research programs are: biogeochemical dynamics, ecological systems and dynamics, climate and hydrological systems, the interactions between natural processes and human activities, the study of past natural changes n earth system history, interactions between the earth's surface and the atmosphere, hydrosphere, cryosphere, and biosphere, and solar influences. Forest Service esearch is aimed specifically at forest and range systems and includes the effect of the atmosphere on ecosystems (changing physical and chemical environments), the effects of ecosystem change on the atmosphere (biogenic emission of gasses, land management influences), long-erm changes in ecosystems, and the prediction of ecosystem responses (USDA Forest Service 1988).

The Future

While we have yet to detect the first signals of greenhouse warming, either through direct measurements of emperature or through impacts on forest ecosystems, we need to begin preparing for the inevitable changes. Our policy options are to conserve what we currently have n forest resources, to develop strategies to mitigate the effects of climate change, to adapt to change, or some combination of these three options. Each of these options raises many questions concerning management actions and our understanding of forest ecosystems.

The conservation option is undoubtedly the most difficult to achieve. In those areas where forest productivity will be significantly reduced, many resources will be diminished. While we could conserve some elements, albeit at a high cost, the external force, climate, will ultimately prevail. Different ecosystems will evolve in those areas where the future climate significantly differs from the current situation. Conservation actions might include installation of irrigation systems in plantations, or use of fertilizers to compensate for reductions in growth rates. Solomon and West (1987) suggest that it is uncertain whether it would be possible to maintain the net productivity of commercial forest lands in the United States under climate change. The implementation of such conservation actions raises a policy question of future land use. Which forest types should be conserved, if any, and where should they be conserved? Competition for land use will be strong because other uses, such as agriculture or urban area, will also be adjusting to climatic change.

The second option, that of mitigating the effects of climate change, involves the global community. Energy conservation or use of nonfossil fuel energy will slow global warming. Such actions require a global policy rather than a local land management policy. Energy conservation or use of alternate energy sources can control the rate of greenhouse gases build-up, but cannot reverse the build-up of greenhouse gases that has already occurred in the atmosphere. Vegetation production removes carbon dioxide from the atmosphere and stores some of it as carbon either in wood aboveground or as roots below ground. Through aggressive reforestation and afforestation, we can offset some of the anthropogenic trace gases. To effectively accomplish accelerated tree planting on nonfederal lands would require close coordination and cooperation among federal and state forestry professionals, consulting foresters, and the tree nursery industry to ensure adequate supplies of quality trees of appropriate species were available to private landowners and local communities. Management questions that need to be answered include what tree species and where. Sustained technical assistance would be required to ensure that proper planting, silvicultural treatments, and tree maintenance take place.

The third option, that of adaptation, offers the greatest flexibility in managing forests in a changing climate. Adaptive strategies involve developing new technologies to utilize the resources of the future forest, importing new industries or businesses which are compatible with the resources of the future forests, or relocating existing activities in anticipation of a changing climate. Adaptive strategies also include developing or introducing species which are compatible with the changing climate. Determining these strategies will involve an examination of questions such as how much and which forest land should be managed for timber production, and what kind of forests. What is the role of federal lands—the location of which was based on a previous climate—in the production of resources, such as timber, forage, water quality and quantity, wildlife, fisheries, and recreation? What is the role of private lands in timber and forage production, water quality and quantity, wildlife, fisheries, and recreation? Land management agencies, such as the Forest Service, are faced with great complexity and the challenge of developing appropriate data bases and models that will provide a reliable basis for decisions about what to do in many different ecosystems and locations and under various conditions which involve a wide range of external variables, in addition to the greenhouse gases.

Because forests are complex ecosystems, and because uses of the forests are so varied, there is no set formula which can be prescribed for all forests. Future forest management will undoubtedly contain elements of all three options to address the problems arising from global change. Because of the uncertainties in the current prediction of impact of climate change on America's forests, we will need to continue careful monitoring and surveillance of our forest ecosystems, particularly those components which are highly sensitive to the greenhouse effect in order to refine management strategies. Also, because our current capability to predict impacts is imprecise, we must continue to carry out research on the effects of multiple stresses on our forests in order to assure their health and productivity in a changing atmospheric environment.

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Projections in the Forest Service Assessment assume a future in which changes in timber production and land use are not abrupt discontinuities from the past. These assumptions may not be met if the earth's climate changes rapidly. This document summarizes the current research on the impacts of climate change on America's forests.

Keywords: Greenhouse effect, timber assessment, ecological response

Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526

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Salmonid-Habitat Relationships in the Western United States: a Review and Indexed Bibliography

Michael D. Marcus
Michael K. Young
Lynn E. Noel
Beth A. Mullan

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Abstract

This report includes a general review and analysis of the literature summarizing the available information relevant to salmonid-habitat relationships, particularly as it pertains to the central Rocky Mountains. Also included is a comprehensive indexed bibliography.

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February 1990

Salmonid-Habitat Relationships in the Western United States: a Review and Indexed Bibliography[1]

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Lynn E. Noel
Beth A. Mullan

[1]*This report was prepared by personnel of Western Aquatics, Inc., 203 Grand Avenue, Laramie, Wyoming, by agreement with the Rocky Mountain Forest and Range Experiment Station, Laramie, Wyoming. Station headquarters is in Fort Collins, in cooperation with Colorado State University. Michael K. Young is currently a Research Fisheries Biologist with the Rocky Mountain Forest and Range Experiment Station, Laramie, Wyoming.*

Preface

Western lands administered by the USDA Forest Service contain many valuable natural resources, including prominent and highly valued salmonid fisheries. Land management activities can directly affect a large proportion of these fisheries, since most streams inhabited by these fish originate on national forests. But the present Forest Service fish habitat research program is small compared with the extent of the fishery resources on national forests and the technical knowledge required to manage these resources. Recognizing the necessity to augment ongoing research efforts and to expand management options, the Rocky Mountain Forest and Range Experiment Station of the Forest Service requested a literature review on salmonid-habitat relationships in the Western United States.

Contents

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EXECUTIVE SUMMARY

This report reviews and analyzes the literature to sum-
arize the available information relevant to understand-
ig salmonid-habitat relationships in the Western United
tates. Influences by many physical, chemical, and bio-
gical variables on salmonid habitats are summarized.
nformation considered includes the natural range of var-
tion in these variables, how these variables interact,
hich of these variables are most important, and how
rest use affects these natural relationships and impacts
e quality of salmonid habitats. Some available manage-
ent alternatives to mitigate these impacts are briefly
iscussed. Also, general guides to selected literature are
rovided on (1) techniques to restore, rehabilitate, and
nhance salmonid habitats; and (2) methods to monitor
nd evaluate habitat quality for salmonids. Important
oncerns on the development and use of salmonid-
abitat models are reviewed. Our discussion draws heav-
y on the findings and conclusions from many previ-
us reviewers, while it also highlights additional results
om some more recent studies. Overall, our literature
eview shows that proportionally little research has been
ompleted in the central Rocky Mountain region on the
elationship of salmonids to their habitats in national
orests.

INTRODUCTION

Western lands administered by the United States
epartment of Agriculture, Forest Service contain many
aluable natural resources, including prominent and
ighly valued salmonid fisheries. Land management
ctivities by the Forest Service can directly affect a large
roportion of these fisheries, since most streams
habited by these fish originate on national forests.
resently, the Forest Service is charged with four mini-
num fish and wildlife objectives, which are to be met
y focusing on habitat manipulation through forest
anagement (Brouha 1987):

- Provide for diversity of plant and animal communities to meet multiple-use objectives and to preserve the diversity of tree species similar to that existing in the region.
- Maintain viable populations of all plant and animal species throughout their existing ranges.
- Accomplish feasible steps to recover threatened and endangered species.
- Maintain and improve habitat carrying capacity for species in public demand.

The existing Forest Service fish habitat research program is small compared with the extent of fisheries resources on national forests and the technical knowledge required to manage these resources. In no Forest Service experiment station are fish habitat needs being fully addressed, although the highly successful research programs at the Pacific Northwest, Pacific Southwest, and Intermountain Stations are helping to meet these needs. Recognizing the necessity to augment ongoing research efforts and to expand available management options, the Rocky Mountain Forest and Range Experiment Station requested a literature review on salmonid-habitat relationships in the Western United States.

The general review and analysis of the literature summarizes available information relevant to salmonid-habitat relationships, particularly as pertaining to the central Rocky Mountains. The common and scientific names for the salmonid species mentioned in the text are shown in table 1. While not all of these species have distributions within the central Rocky Mountains, they are included to help provide insight into the overall biology of salmonid species. Such insight can help guide the formation of appropriate hypotheses for future research in the central Rocky Mountains.

This report does not provide a totally comprehensive review of all work completed that potentially applies to trout-habitat relationships in forest streams of the central Rocky Mountains. This subject is indeed complex and, as later sections show, many good reviews and bibliographies have previously addressed specific facets of these relationships (e.g., Estes 1983, Everest et al. 1985a, Everest and Harr 1982, Leaf 1975a, Platts and McHenry 1988, Reiser et al. 1985, Wydoski et al. 1980). Instead, this report introduces and reviews the principal concerns regarding salmonid-habitat relationships. The discussion draws heavily from the findings and conclusions of the previous reviewers, while also highlighting some findings from more recent studies. Additional reference to much of the earlier literature can be found in these reviews. The indexed bibliography contains over 850 citations of potential interest to fish habitat biologists in the Western United States. These citations were examined but not necessarily cited during our work. (All

literature cited is also contained in this bibliography, rather than in a separate literature cited section.)

ENVIRONMENTAL VARIABLES AFFECTING SALMONIDS AND THEIR MANAGEMENT

The quality of salmonid habitats is defined through interactions among a diversity of physical, chemical, and biological variables. Cultural developments have and will continue to affect these natural interactions. Our knowledge of the natural range of variation for these variables, how these variables interact, which of these variables are most important, and how our cultural activities affect these natural relationships and impact the quality of salmonid habitats is continuing to grow through extensive research efforts and experience. But many questions remain.

The following report summarizes much of our present knowledge on these relationships. In discussing specific sources of potential impact, we often provide brief considerations of some available management alternatives to mitigate these impacts on salmonid habitats. Two general guides are included: a guide to some of the techniques available for restoring, rehabilitating, and enhancing salmonid habitats; and a guide to methods available for monitoring and evaluating salmonid habitat quality. Then, the development and use of models for salmonid-habitat relationships are discussed.

Table 1.—Common and scientific names of salmonids mentioned in this report.[1]

Common name	Scientific name
Golden trout	*Oncorhynchus aguabonita* (Jordan)
Cutthroat trout	*Oncorhynchus clarki* (Richardson)
Lahontan cutthroat	*Oncorhynchus clarki henshawi* (Gill and Jordan)
Yellowstone cutthroat	*Oncorhynchus clarki lewisi* (Simon)
Snake River cutthroat	*Oncorhynchus clarki pleuriticus* (Simon)
Greenback trout	*Oncorhynchus clarki stomias* (Simon)
Pink salmon	*Oncorhynchus gorbuscha* (Walbaum)
Chum salmon	*Oncorhynchus keta* (Walbaum)
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Rainbow trout	*Oncorhynchus mykiss* (Richardson)
Sockeye salmon (kokanee)	*Oncorhynchus nerka* (Walbaum)
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
Pygmy whitefish	*Prosopium coulteri* (Eigenmann and Eigenmann)
Mountain whitefish	*Prosopium williamsoni* (Girard)
Brown trout	*Salmo trutta* Linnaeus
Bull trout	*Salvelinus confluentus* (Suckley)
Brook trout	*Salvelinus fontinalis* (Mitchill)
Dolly Varden	*Salvelinus malma* (Walbaum)
Lake trout	*Salvelinus namaycush* (Walbaum)
Arctic grayling	*Thymallus arcticus* (Pallas)

[1]*Names follow Baxter and Simon (1970), Robins et al. (1980), and Smith and Stearley (1989).*

NATURAL DETERMINANTS OF HABITAT QUALITY FOR SALMONIDS

Successful survival and reproduction by aquatic organisms is broadly defined by the physical structure in the environment, the quality of the surrounding waters, and interactions with other organisms. In streams of the central Rocky Mountains, the principal characteristics of environmental structure that influence salmonid abundance and population structure include riparian vegetation, channel morphology, streamflows, deposited sediment, and winter snow and ice accumulation. Important water quality characteristics include suspended sediment, temperature, pH, nutrients, and potentially toxic chemicals. Biological influences involve nutrient and energy cycles, interactions with invertebrates, competition with and predation by other fish, and predation by birds and mammals.

Riparian Vegetation

Riparian vegetation consists of nonaquatic vegetation that directly influences the stream (Meehan et al. 1977). Its influence on streams is inversely proportional to stream size, with first- to fourth-order streams tending to be strongly controlled by riparian vegetation (Meehan et al. 1977). Control operates through physical influences on channel structure and chemical influences on organic and inorganic contributions to the stream (Cummins et al. 1984, Lowrance et al. 1984, Sedell and Dahm 1984, Sedell and Froggatt 1984). Specifically, riparian vegetation provides streams with bank stability, trout cover, moderating influences on water temperatures, large organic debris (LOD), and contributions of energy and nutrients (Meehan et al. 1977, Moring et al. 1985, Platts 1983b).

Streambank Stability

Li and Shen (1973) stated that vegetation creates roughness that decreases water velocity and reduces the erosivity of overbank flows. Though this decrease in water velocity tends to increase the height of flood peaks, bank erosion still declines (Schumm and Meyer 1979). Decreased water velocity reduces the ability of water to carry sediment; thus riparian zones are sites of sediment deposition (Lowrance et al. 1984). Bank will form through this deposition on the convex shoreline, e.g., inside of the meanders (Platts 1983b). Furthermore, aboveground vegetation reduces rainsplash erosion, animal damage, and ice transport damage on stream banks (Platts 1983b). Roots increase the resistance to substrate erosion of banks (Meehan et al. 1977). Compared with poorly vegetated sites on a Utah stream, a well vegetated reach on the same stream resisted undesirable changes in morphology related to trout habitat (increased width, increased bank angle, and decreased amount of undercut bank (Platts et al. 1985)).

over

Cover has been difficult to define; it relies on the ssumption that sites occupied by trout possess cover. utler and Hawthorne (1968) concluded that cover nbraces elements of shade or shadow. Binns and Eiser-an (1979) defined cover as any bank or channel feature that allows trout to avoid the impact of the elements or nemies.'' Such features include overhanging vegetation, ndercut banks, submerged vegetation or objects, water epth, and water turbulence (Reiser and Bjornn 1979). esche (1980) suggested a quantitative definition: cover onsists of sites deeper than 15 cm with water velocities ss than 15 cm/s in the presence of one or more of the orementioned features. A more specific definition of over, useful for salmonids in streams of the central Rocky ountains, employs three components: (1) areas of cob-e or boulder (substrate greater than 7.5 cm in diameter) water at least 15 cm deep; (2) overhead bank cover ndercut banks, overhanging vegetation, logs, or debris ms) at least 9 cm wide and associated with water at least cm deep; and (3) pools with water depths greater than 5 cm (Wesche et al. 1985a, 1987a). Riparian vegetation rectly affects the second component.

Field evidence suggests that salmonids respond to ianges in cover provided by riparian vegetation. Baldes id Vincent (1969) noted that brown trout tended to cupy shaded locations within a flume. Brown trout and ook trout in a submerged tank occupied sites shaded artificial overhangs 84% and 72% of the time, respec-vely (Butler and Hawthorne 1968). DeVore and White 978) found that brown trout preferred artificial over-ıngs close to the water surface in conjunction with tac-le stimuli similar to submerged, trailing branches. oussu (1954) reported that brook trout and rainbow trout anding stocks responded to artificially manipulated nounts of overhanging bank cover in a Montana stream. nd Wesche et al. (1987a) found that a model using only e amount of overhanging bank cover, compared with odels incorporating additional cover components, edicted the greatest amount of variation in brook trout id brown trout standing stocks in small Wyoming reams. The two-variable model predicting the greatest nount of variation in brown trout standing stocks in outheastern Wyoming included overhanging bank cover one variable (Wesche et al. 1987b).

Nonetheless, the influence of overhanging bank cover trout standing stocks is not entirely understood. espite the frequent correlation between overhanging ank cover and trout standing stocks, this relationship in be confounded by inconsistencies associated with out species and channel type (Kozel 1987). Brook trout id Atlantic salmon selected shaded sites in water less ian 25 cm deep, but showed no preference for shade in ater over 50 cm deep (Gibson and Power 1975). In a boratory study, Wilzbach (1985) found that cutthroat out only associated with artificial overhanging or sub-rate cover at high food abundance, and she suggested iat "cover" may interfere with foraging efficiency. Addi-onally, Schutz and Northcote (1972) reported that cut-iroat trout foraged much less successfully at low light intensities than at high light intensities. Helfman (1981) stated that shaded fish can detect prey more easily than can unshaded individuals, and that shaded fish more readily avoid detection by unshaded predators. But these advantages are lost if both the prey and predator are shaded.

Water Temperature

Brown et al. (1971) suggested that stream water temperature was a function of global and net radiation, convection, conduction, evaporation, and storage. Platts (1983b) stated that direct solar radiation accounts for 95% of the heat input into Rocky Mountain streams during summer at midday. Furthermore, stream temperature is directly proportional to heat input, as affected by solar angle and time of day, and exposed stream surface area, while it is inversely proportional to stream discharge (Meehan et al. 1977). Riparian vegetation can also reduce heat loss to the atmosphere during winter; such loss can cause anchor ice formation and lead to substrate disturbance (Platts 1983b). Thus, shading by riparian vegetation often tends to moderate stream temperatures year-round.

Shading may prevent water from attaining temperatures stressful or lethal to salmonids. Many salmonids tolerate temperatures near 18°C, but higher temperatures may increase stress, and mortality typically occurs near 25°C (Jobling 1981). Riparian vegetation prevented water from incurring stressful temperatures in a Pennsylvania stream during summer, but temperatures often exceeded 21°C after removal of this vegetation (Lynch et al. 1984).

Yet shading influences salmonids in a variety of ways in addition to reducing foraging efficiency. Murphy and Hall (1981) compared clearcut, second-growth, and old-growth sites along Oregon streams, and found that reaches in clearcuts possessed the least shade but contained the greatest densities of coastal cutthroat trout. Hawkins et al. (1983) concluded that unshaded reaches supported greater standing stocks of salmonids in West Coast streams because the increased light intensity increased primary production of algae, which augmented secondary production of benthic invertebrates, thus boosting the number of drifting insects available to trout.

Large Organic Debris

Large organic debris (LOD) has been variously defined as any woody material greater than 2.5 cm in diameter (Harmon et al. 1986); as logs, limbs, and rootwads at least 10 cm in diameter (Keller and Swanson 1979); and as wood at least 2 m long and with one end greater than 30 cm in diameter (Bryant 1985). Whatever its definition, LOD has both physical and biotic impacts on salmonid streams. Physical impacts include changes in stability of streambanks and channels, storage of sediment, dissipation of stream energy, and alteration of channel flows (Bryant 1983, Everest and Meehan 1981a, Harmon et al. 1986).

Streambank cutting, windthrow, ice loading, avalanches, and debris torrents contribute LOD to stream

channels; and abrasion, biological decomposition, debris torrents, and flotation at high flows remove LOD (Keller and Swanson 1979). Density of LOD tends to be highest in first-order streams because the wood-contributing area to stream area ratio is the highest, and because stream power is lowest (Keller and Swanson 1979). Stream power also determines distribution of LOD within streams; LOD occurs at random in first- and second-order streams, is redistributed within the channel in third- to fifth-order streams, and develops patchy distributions of debris jams in larger streams (Harmon et al. 1986).

When LOD is deposited in streams, several variables determine whether the debris will be stably incorporated into the channel or displaced downstream during high flows. Bilby (1984) noted that pieces larger than 10 m long and 75 cm in diameter, with both ends and one "face" buried, were the most stable. Further, debris that had been in place over 5 years, resisted decomposition, and bridged the entire channel generally remained stable, but usually only if stream gradient was less than 10% in high-order streams (Bryant 1983). Residence of stable LOD may exceed 100 years (Swanson and Lienkaemper 1978).

Unstable LOD may cause erosion during high flows by abrasion, and unstable accumulations may result in debris torrents, which produce relatively smooth, U-shaped channels that terminate in huge debris jams in low-gradient reaches (Bryant 1983, Swanson and Lienkaemper 1978). Alternatively, the removal of stable LOD also induces erosion. Bilby (1984) reported that debris removal from a fourth-order Washington stream reduced bed elevation by an average of 25.4 cm after the first high flow. After debris removal from an Oregon stream, mean scour depth was 90 cm (Beschta 1979).

Single logs may block the entire channel and form steps. These log steps reduce water velocity upstream and trigger sediment deposition (Heede 1985). LOD-influenced sediment storage is more important in high-gradient streams lacking hydraulic storage of sediment (Keller and Swanson 1979). Swanson and Lienkaemper (1978) suggested that less than 10% of the sediment stored in streams with abundant LOD is transported during yearly high flows. Beschta (1979) estimated that 21 m^3 of fine sediment per meter of stream were stored above log steps. Prior to debris removal, log steps stored 87% of the fine sediment in a New Hampshire stream, but after cleaning, the stream lost 83% of its sand and silt (Bilby 1981).

Small waterfalls form plunge pools on the downstream side of log steps. This stepped gradient causes much of the stream channel to have a lower gradient than the valley bottom and dissipates stream energy (Swanson and Lienkaemper 1978). Heede (1981b) found water velocities of less than 12 cm/s in plunge pools, despite velocities up to 61 cm/s above and below these pools. In several western Oregon streams, LOD influenced 30–80% of the drop in stream elevation (Keller and Swanson 1979). Debris dams were responsible for 52% and 46% of the drop in first- and second-order streams, respectively, in a New Hampshire forest (Bilby 1981). Heede (1985) noted that log steps and transverse gravel bars both act to dissipate stream energy. If the former are removed or absent, the stream will transport bedload to form the latter. But if adequate substrate is unavailable, the stream width will increase, meandering will decrease, while longitudinal distance and, hence, downcutting will increase (Heede 1985).

The orientation and size of LOD in streams can increase channel heterogeneity by altering flow direction and velocity (Everest and Meehan 1981a). Following the first high flows after a Washington stream was cleaned, the number, area, and volume of pools decreased, while the area and volume of riffles increased (Bilby 1984). Channel heterogeneity relates to the biotic impacts of LOD, because salmonids preferentially occupy main channel, near shore, and side channel habitats influenced by LOD (Harmon et al. 1986).

LOD can reduce the habitat quality of salmonid streams by decreasing channel stability (as described above), by reducing water quality, or by blocking migration. Peters et al. (1976) reported that some organic chemicals in the heartwood (tropolones) and foliage (terpenes) of western red cedar (*Thuja plicata*) were toxic to fry of coho salmon, and that lethal concentrations developed in streams contaminated with logging wastes. Yet, Harmon et al. (1986) suggest that oxygen depletion will occur prior to reaching toxic concentrations of conifer leachates. Sedell and Luchessa (1982) noted that excessive woody debris can block the upstream migrations of anadromous fish, particularly in low-order streams. But debris dams rarely completely block fish passage, and such blocks may only be seasonal (Bryant 1983).

Many juvenile anadromous salmonids, especially coho salmon, heavily use cover created or influenced by LOD. Side channels created by LOD in large rivers are used far in excess of their availability by coho salmon smolts (Sedell and Luchessa 1982). M. D. Bryant (1985) found that age 0 and 1 coho salmon were more abundant in reduced-velocity channel edges controlled by LOD than along edges lacking LOD. Midwinter densities of juvenile coho salmon were significantly positively correlated with debris volume, and coho microhabitats were always associated with LOD (Tschaplinski and Hartman 1983). After debris removal from a southeastern Alaska stream, the abundance of age 1 coho salmon declined (Bryant 1982). Lister and Genoe (1970) stated that recently emerged coho and chinook salmon associated with cover provided by LOD. Following selective removal of LOD from two Alaska streams, densities and production of age 0 and 1 coho salmon and age 1 and 2 Dolly Varden decreased (Dolloff 1986). During winter at water temperatures below 9°C, age 0 and 1 coho salmon and age 1 steelhead occupied microhabitats within 1 m of LOD (Bustard and Narver 1975b).

Other anadromous and resident species also respond to the presence of LOD. Bisson et al. (1982) noted that age 0, 1, and 2 cutthroat trout associated with woody debris in pools, and that age 0 and 1 steelhead were found near LOD in riffles. The mortality of brown trout fry was greater in a stream subjected to weed and debris removal than in a nearby control stream (Mortensen 1977). Lestelle and Cederholm (1984) discovered that cutthroat trout populations in a cleaned stream did not decline until

winter, and the population recovered within 1 year. However, the volume of instream LOD had also recovered to pretreatment conditions.

Nutrient and Energy Effects

Riparian vegetation can act as a sink that removes nutrients and particulate sediment from water prior to entry into streams (Karr and Schlosser 1977, Lowrance et al. 1984). But perhaps the more important role of riparian vegetation is in providing the organic materials that provide the principal energy base for instream biota. Often, the morphological characteristics of allochthonous detritus (i.e., detritus input from sources external to the stream channel) define the microbial and invertebrate communities and, consequently, the energy bases for fish inhabiting these waters (Cummins 1973, 1974; Cummins et al. 1984; Minshall et al. 1982; see Short et al. 1980 for results from the central Rocky Mountains).

Among the characteristics of debris that are important determinants of community composition are the types, sizes, and physical and biochemical compositions of riparian material inputs. These characteristics in turn help define the rates at which debris from the riparian vegetation will decompose in the channel. Note, however, that not only are plant materials from riparian vegetation important contributors to the energetics of stream communities, but terrestrial insects flying or falling from these plants also provide important contributions to the nutrient and energy inputs to stream communities (Cada et al. 1987a, Meehan et al. 1977).

Allochthonous inputs can contribute up to 100% of the organic material ingested by some invertebrate taxonomic groups in streams (Minshall 1967). In some running water systems, however, with limited growths of riparian vegetation (e.g., some high alpine, sagebrush, and grassland areas) autochthonous productivity (i.e., productivity by sources within the stream) can dominate these systems, at least during some times of the year (Minshall 1978). (See the section Natural Determinants of Water Quality and Energy Dynamics in Streams for additional discussion of the influence of riparian vegetation on stream energetics, and the section Instream Biological Relationships for additional information on fish-invertebrate interactions.)

Channel Morphology

Physical features in stream channels are a primary determinant of the types and quality of fish habitat. These physical habitat features include streambed gradient, water depth, water velocity, substrate, and cover (Stalnaker and Arnette 1976). This section discusses the relationships affecting the morphology of stream channels.

The morphological and hydraulic characteristics of stream channels are determined by the flow regime, and environmental factors such as geology, climate, and vegetation (Heede 1980). Several authors have documented changes in channel size and shape with changes in the flow regimes (Bray and Kellerhals 1969, Petts 1977, Williams 1978, Williams and Wolman 1984). Others have shown the effects of environment on channel morphology (Hynes 1970, Leopold and Maddock 1953, Osterkamp and Hedman 1982, Richardson et al. 1975). Andrews (1980) concluded that perennial stream channels are naturally adjusted to their bankfull flows. Paraphrasing Hynes' (1970) and Heede's (1980) summaries on the dynamics of stream channels:

> The main channel tends to swing from side to side, even in relatively straight reaches of stream, causing the channel pattern to continually change. When a stream rounds a curve, the main current hugs the outside, concave bank and the momentum of the water causes the stream surface to become banked. Here, the water in contact with the bank is slowed by friction. As the stream slows, it flows downward and inward, eroding the concave bank downward and outward. Meanwhile, material is being deposited on the inside, convex bank of the curved channel. The wave length of meanders are generally 7 to 10 times the width of the stream, while the actual path measured along the channel itself is about 11 to 16 times the width. Riffles tend to occur at a frequency of about 5 to 7 times the width, particularly in gravel-bed streams, and tend to remain rather stationary. They rarely occur in sandy bottomed streams. Where the channel substrate is loosely consolidated (e.g., in glacial outwash gravels), braided or reticulate channels can form.

Steep drainages in mountain regions of the Western United States pose potentials for high erosion and production of deeply incised channels and greatly steepened valley slopes (Heede 1980). To counter these potentials, natural mechanisms exist that allow streams to adjust channel slopes, which help to protect streambeds. These mechanisms include (1) bed armoring by gravel and boulders, (2) gravel bars that form transverse to streamflows, and (3) log steps that incorporate fallen timber and associated debris into the streambed. Transverse gravel bars and log steps often create longitudinal profiles with steps spaced at regular intervals; and when log steps are lacking the incidence of transverse gravel bars tend to increase. Both of these mechanisms essentially stop the flow in places. Heede (1980) suggested that while such natural flow adjustments were temporary, their continual, natural replacement created a "dynamic equilibrium" between the stream's erosive forces and the stream's beds and banks. By manipulating the number of dead and dying trees in the streamside forest, the manager can influence the hydraulic nature of small streams. Lisle (1986b) found that most pools and upstream gravel bars are associated with large streamside obstructions and bends; based on his observations he developed a general model to define these relationships.

The relation of trout standing stock to channel stability is equivocal. Using the Stream Reach Inventory and Channel Stability Evaluation (SRICSE), developed by Pfankuch (1975) to assess overall channel stability for streams in the central and northern Rocky Mountains, Eifert and Wesche (1982) noted that the mid to high

SRICSE scores and six of its variables (bank cutting, deposition, substrate brightness, particle packing, stable materials, and scouring and deposition) had significant negative correlations with standing stocks of brown trout in two southeastern Wyoming streams. That is, as channel stability (as indicated by SRICSE scores) increased, actual channel stability and standing stocks decreased. The abundance of young Dolly Varden was positively correlated with stream channel stability in an Alaskan stream (Murphy et al. 1986). Nonetheless, Dunham and Collotzi (1975) considered moderate SRICSE scores optimal for trout habitat. And Kozel (1987) found that overall SRICSE scores and individual variable scores were inconsistently related to standing stocks of brook and brown trout.

Rosgen (1985) has developed a stream classification system that categorizes various stream types by morphological characteristics, including stream gradient, sinuosity, width-depth ratio, channel materials, entrenchment, confinement, and soil/landform features. Using Rosgen's classification in the Medicine Bow National Forest, Wyoming, Kozel (1987) found that in B channels brook trout habitat characteristically had narrow channels with abundant overhanging cover and back pools with aquatic vegetation; brown trout habitat was typified by deep, dammed pools (≥15 cm). Though both brook and brown trout typically inhabited narrow channels in C channels, abundant aquatic vegetation providing pool cover characterized brown trout habitat. Overall, C channels had greater standing stocks of trout than did B channels. In another study from southeastern Wyoming, Chisholm and Hubert (1986) found that stream gradient was negatively correlated with standing stocks of brook trout. And, Lanka et al. (1987) found that using geomorphic variables for Wyoming watersheds alone predicted standing stocks of trout as well as did stream habitat variables; the best predictor of trout abundance used both geomorphic and instream variables.

Streamflows

Runoff volumes to streams usually follow seasonal patterns of precipitation, generally with great overall variation (e.g., Parrett and Hull 1985). In mountainous headwater streams of the West, snowmelt provides most of the annual streamflow, with flow peaking from May to July. Minimum streamflow occurs during the fall and winter, and consists largely of groundwater influxes.

Few continuously recording streamflow gaging stations have been established in small mountain drainages having less than 260 km^2 (100 mi^2). In one approach to estimate stream discharge for such systems, both Hunt (1963) and Riggs (1969) determined that annual discharge at an ungaged site could be estimated with an error of 10% using ratios between point measurements for ungaged streams and measurements for the same day from a nearby gaged stream site. Lowham (1976) developed empirical equations using channel size or watershed characteristics to predict mean annual and peak flows for small watersheds in Wyoming.

In an alternative approach, Parrett and Hull (1985) used regression to relate both mean and long-term annual discharges to drainage area and annual precipitation. They also developed equations to predict probabilities of flows that would exceed predicted annual flows. While equations developed by such approaches tend to have localized applications, similar methods can be used to estimate streamflows in other ungaged drainages.

Streamflows may be thought of as having "subcritical" and "supercritical" velocities (Heede 1980). Subcritical flows exert relatively low energies on banks and beds, while supercritical flows can produce highly erosive force and cause channel damage. Standing waves are commonly associated with supercritical flows.

Periodic high streamflows that flush fine sediment from the deeper bed layers are necessary to maintain the channel and riparian habitats (Reiser et al. 1985, 1987). Such flows prevent vegetative encroachment into the channel and encourage plant succession in riparian zones, thereby maintaining and enhancing fishery habitat.

Fine Sediment

Though researchers do not agree on the exact size of fine sediment, it is generally less than 6.3 mm in diameter (Chapman 1988). Sediment transport in streams is a very complex relationship involving at least 30 variables (Heede 1980). But, in general, transport of fine sediment may be via saltation along the stream bottom or suspension in the water column, with discharge and channel slope proportional to the quantity and size of transported sediment (Hasfurther 1985). Typically, transport of sediment is greater on the ascending limbs of storm hydrographs, but this is due more to the supply of sediment rather than the hydraulics of the flows (Sidle 1988, Sidle and Campbell 1985).

Everest et al. (1987) suggested that some fine sediment may be beneficial to salmonids by contributing to increased invertebrate productivity, and that the adverse consequences of fine sediment introduction to trout streams have been overstated. Nonetheless, the transport and deposition of fine sediment frequently are assumed to deleteriously affect survival throughout the life history of salmonids.

Turbidity is a measure of the scattering and absorption of light by dissolved and particulate matter in water (Lloyd 1987). Usually, turbidity and suspended sediment concentration are highly correlated; thus, turbidity can provide an index of suspended sediment concentration (SSC) (Lloyd et al. 1987). Because murky water absorbs more heat than clear waters, increased suspended sediment loads can cause water temperatures to increase (Hynes 1970). Water with a temperature of 5°C is able to carry 2 to 3 times more sediment than 27°C waters (Heede 1980).

SSC may directly or indirectly influence the survival of salmonids (Iwamoto et al. 1978). SSC can affect fish directly by clogging and damaging respiratory organs; laboratory and field studies have shown that the extent of this impact depends highly on the size and composition

the suspended material and on the individual species fish (e.g., Branson and Batch 1972, Everhart and ıchrow 1970, Herbert and Richards 1963). Redding and :hreck (1980) and Redding et al. (1987) found that high SC elevated several physiological measures of stress in venile coho salmon and steelhead. Over 50% of juvenile oho and chinook salmon died after a 96-hour exposure water containing about 500 mg/L of SSC (Stober et al. 81). SSC above 100 mg/L have reduced survival of juven- e rainbow trout (Herbert and Merkens 1961). Reductions growth or feeding of salmonids were associated with rbidity over 25 nephelometric turbidity units (NTU))lson et al. 1973, Sigler et al. 1984, Sykora et al. 1972). nce salmonids are considered to be sight-feeders, the duction in light transmission caused by high turbidity ay result in less feeding and decreased growth (Berg 82). In response to turbidity, salmonids may change eir use of cover or reduce territoriality (Berg and North- te 1985, Gradall and Swenson 1982). When given the portunity, juvenile coho salmon avoided turbid water isson and Bilby 1982). Despite these impacts, salmonids ten successfully inhabit streams with seasonally high rbidities, perhaps due to behavioral modifications and limited exposure to concentrated suspended sediments.

Deposition of fine sediment can acutely affect survival salmonids (1) during intragravel incubation of eggs and evins; (2) as fingerlings; and (3) throughout winter hapman and McLeod 1987). Timing, source, and quan- y of deposited sediment can affect survival. Winter ak flows, and thus sediment transport and deposition, rrespond with the incubation of eggs and alevins of lmon and steelhead in the Pacific Northwest (Meehan d Swanston 1977). But cutthroat and rainbow trout in e central Rockies spawn after the spring peak flows, d redd substrates may change very little throughout cubation (Young et al. 1988).

Duncan and Ward (1985) demonstrated that the per- ntage of fine sediment in 12 southwestern Washington reams was more closely related to the percentage of the atershed composed of sedimentary rock than to the per- ntage of watershed area in roads. They noted that a ream draining a heavily roaded watershed composed soils derived entirely from volcanic rock had a lower oportion of fine sediment in the stream channel, com- ared with channels in watersheds largely composed of ndstones and siltstones.

Increasing proportions of fine sediment in substrates ave been associated with reduced intragravel survival embryonic brook trout (Hausle and Coble 1976), brown out (Witzel and MacCrimmon 1983a), cutthroat trout rving and Bjornn 1984), rainbow trout (Witzel and Mac- rimmon 1981), steelhead (Tappel and Bjornn 1983), and arious species of Pacific salmon (McNeil and Ahnell 964, Phillips et al. 1975). But increases in fine sediment n directly limit survival-to-emergence only by entrap- ing alevins (Koski 1975); the potentially greater fluence on survival by increased sediment deposition the decrease in dissolved oxygen concentration cou- led with reduced intragravel water flow (Chapman 988). For example, Sowden and Power (1985) found no orrelation between the amount of fine sediment in redds and the survival-to-emergence of rainbow trout, but they did report that reduced survival in redds was significantly correlated with both reductions in intragravel flows and in dissolved oxygen concentrations. Furthermore, most studies evaluating the impacts of fine sediment on embryonic survival have been conducted in the laboratory; few or no field studies have satisfactorily quantified actual impacts (Chapman 1988).

Fingerling density has often been associated with low concentrations of fine sediment deposited between and on the surface of larger substrate particles. This is defined as embeddedness (Burns and Edwards 1985). Crouse et al. (1981) found that production of coho salmon increased as embeddedness decreased. After the installation of a sediment trap, the abundance of juvenile brown and rainbow trout in a Michigan stream increased by 40% (Alexander and Hansen 1983). Following the experimental addition of fine sediment to a Michigan stream, brook trout densities declined by more than 50% (Alexander and Hansen 1986). Klamt (1976) suggested that fine sediment filled in pools and interstices between cobble, thus reducing the amount of habitat available to fingerling and adult salmonids. Nonetheless, Chapman and McLeod (1987) reported that the relation between the rearing densities of salmonids and fine sediment was equivocal, citing several studies demonstrating no or a positive relation between fingerling abundance and embeddedness. They suggest that changes in stream morphology caused by fine sediment may outweigh the effects of embeddedness on fingerling survival.

As indicated in a later section, declining water temperatures in winter may cause salmonids to seek refuge within the interstitial spaces of the substrate. Bjornn (1971) noted that more juvenile steelhead trout left experimental channels containing large amounts of fine sediment than those containing little or no fine sediment. Deposition of fine sediment could also restrict winter cover for adult fish by filling in low-velocity habitats, e.g., pools and undercut banks (Bjornn et al. 1977a). Very little additional research has been conducted to quantify the effects of fine sediment on winter habitat in the western United States.

The ongoing Sediment-Fish Response Project at the University of Wyoming is investigating the impact of fine sediments on embryonic salmonids in the intermountain Rocky Mountains (Young et al. 1988). Building on previous work completed in the northeastern and northwestern United States, this project is focusing on estimating survival-to-emergence (STE) for embryonic salmonids in the laboratory under realistic conditions; on quantifying the spatial and temporal differences in the substrate between egg pockets, redds, and undisturbed sites; on defining the best field measures for evaluating substrate and intragravel flows; on developing and refining a model for STE; and on validating this model with field investigations.

Snow Cover and Ice

Winter alters trout behavior and affects survival by changing the physical habitat of trout. Among the most

obvious changes are reduced water temperature and increased ice formation and snow cover. Declining temperatures in autumn may cause a variety of responses in salmonids. Bjornn (1971) noted that juvenile salmon and trout moved downstream as water temperature decreased, and he attributed this to a lack of suitable substrate (rubble with large interstices between particles); significantly more fish left troughs containing gravel than left troughs containing rubble. In a field experiment, Chapman and Bjornn (1969) found that 7% of the juvenile steelhead left a trough filled with coarse rock, but 35% left a trough filled with gravel. While most steelhead entered the substrate when temperatures fell below 5°C, juvenile coho salmon apparently did not enter the substrate during winter. Yet Rimmer et al. (1983) found that over 90% of immature Atlantic salmon entered the substrate when temperatures dropped below 10°C. And Hillman et al. (1987) stated that winter rearing densities of chinook salmon increased over eightfold after cobble was added to a section of an Idaho stream, presumably due to the increased availability of interstitial space. In fact, juvenile steelhead have been found up to 15 cm deep in substrates during winter (Edmundson et al. 1968).

As winter progresses, one or more types of ice may develop. Shelf ice forms along the streambank and may eventually cover the entire stream (Johnson et al. 1982). Anchor ice forms on the stream bottom when a streambed radiates energy to the sky (usually during clear conditions) causing water temperatures to decline below 0°C (Benson 1955). Frazil ice consists of smaller crystals suspended in the water column (Maciolek and Needham 1952).

Salmonids occupy sites beneath shelf ice, suggesting it provides suitable overhanging cover (Logan 1963, Maciolek and Needham 1952). Cunjak and Power (1987) noted that both brown trout and brook trout occupied areas beneath submerged artificial overhangs in an ice-free Ontario stream. In an ice-free Cascade Mountain stream, rainbow trout occupied pools during the day, but tended to enter the spaces in the substrate as temperatures declined from 13°C to 8°C (Campbell and Neuner 1985). But these fish reappeared at night in shallow, near-shore sites and remained there until approximately 1 hour before dawn, when they reentered the substrate. Needham and Jones (1959) also observed more trout in the water column at night than during the day in the winter in a California stream. Thus cover, as shelf ice, overhanging vegetation, substrate, or darkness, apparently influences winter behavior of salmonids.

Both brown and brook trout have been found to occupy low-velocity sites (<15 cm/s) under complete ice or snow cover (Chisholm et al. 1987, Wichers 1978). However, ice cover reduces available habitat; Chisholm et al. (1987) noted that ice excluded from 64% to 84% of the cross-sectional area of one section of a southeastern Wyoming stream. Streams completely covered with snow have little or no ice formation and provide very stable habitat conditions. Johnson et al. (1978) devised a model to predict habitat excluded by ice based on the days since the winter solstice, solar radiation, mean water depth, and mean water velocity.

Ice or snow may be associated with mortality in other ways. As water temperature increases, anchor ice may detach from the stream bottom to form ice dams; flows continually redirected by these dams may eventually strand trout (Maciolek and Needham 1952, Needham and Jones 1959). This detachment may also dislodge aquatic insects and increase turbidity (Maciolek and Needham 1952). Needham and Slater (1944) reported that the collapse of a snowbank killed over 300 trout. Ice forming in the substrate may cause mortality of the embryos of fall-spawning salmonids (Benson 1955, Reiser and Wesche 1979). However, Olsson (1981) reported that most benthic invertebrates survived intragravel freezing, and he suggested that freeze tolerance removed the need to seek flowing water that might expose invertebrates to predation.

Finally, winter conditions affect the feeding behavior of trout and, consequently, their physiology. Reimers (1957) found that wild brown trout starved for 180 days suffered only 8% mortality. Also, these fish required up to 70 hours to assimilate a 5-g meal at 0°C. Hatchery trout tended to die in early spring as water temperatures increased, apparently because they lacked energy reserves to meet the increase in metabolic activity (Reimers 1963). Hunt (1969) noted that the overwinter survival of fingerling brook trout increased as fingerling size increased, and he attributed this to a greater resistance to temperature-induced physiological stress in larger individuals.

Natural Determinants of Water Quality and Energy Dynamics in Streams

The natural physical and chemical qualities of waters in streams are determined by (1) volume, frequency, and chemical nature of precipitation; (2) physical and chemical nature of the underlying parent rock and soil that these waters flow over and through; (3) chemical changes to the waters in the watershed produced via nutrient uptake and decomposition by terrestrial vegetation and microbes; (4) the degree of bank stability and physical shading provided by riparian vegetation; and (5) nutrient uptake by and decomposition of aquatic organisms. This section discusses some of the intensive studies that have been conducted on the relationship between streams and their watersheds, and then briefly reviews two paradigms that currently summarize much of our understanding of nutrient and energy dynamics in flowing water systems. These are "material spiralling" and the "River Continuum Concept."

Stream-Watershed Relationships

For many nutrients and particulate materials, streams transport or accumulate virtually all losses from watersheds, except for often relatively minor losses to the atmosphere. For example, all measurable particulate and dissolved losses of nitrogen from one small watershed passed through or accumulated in the stream, which

comprised <1% of the watershed area (Triska et al. 1984). That study further reported that biotically derived inputs, including litterfall, throughfall, lateral movement, dissolved organic carbon in groundwater and nitrogen fixation, constituted >90% of the nitrogen input to the stream. Leaves, bark, and wood supplied to the stream tended to rapidly leach nitrogen due to physical processes. Subsequently, nitrogen associated with these particles increased due to nitrogen fixation by the stream microflora (Buckley and Triska 1978). Leaf packs having the greatest associated nitrogen contents had the greatest densities of invertebrates. Thus, the capacity of litter microflora to control nitrogen uptake and release apparently influenced directly the production of litter-consuming invertebrates (Triska and Buckley 1978). Microbial communities similarly can be the primary regulator of phosphorus movement in streams (Gregory 1978). In tundra areas the carbon cycle of rivers can be dominated by inputs of eroding particles and leaching of dissolved organic carbon from peat (Peterson et al. 1986).

Intensive studies conducted in cooperation with the USDA Forest Service's Northeastern Forest Experiment Station on the Hubbard Brook Watershed of New Hampshire provide a benchmark for future watershed-stream ecosystem investigations (Likens et al. 1977). These studies found that, while evapotranspiration reduced the volume of water flowing from watersheds, annual evapotranspiration rates were essentially constant over a wide range of precipitation and environmental conditions. Stream water chemistries in the undisturbed forests were highly predictable: concentrations of sodium and silica were diluted by streamflows, while concentrations of aluminum, nitrate, hydrogen, potassium, and dissolved organic carbon increased as streamflow increased. Seasonal biological activities strongly affected the stream concentrations of nitrate and potassium. Atmospheric inputs to the watershed were the major sources for sulfur, nitrogen, chloride, and phosphorus; weathering was the major source for calcium, magnesium, potassium, and sodium; biological activities were the major watershed contributors of carbon and nitrogen; and terrestrial plants served as important impaction surfaces for atmospheric sulfur. Overall, the watershed accumulated nitrogen, sulfur, phosphorus, and chloride, while it lost silica, calcium, sodium, aluminum, magnesium, and potassium. Additionally, Vitousek (1977) found that forest successional stages are important determinates of nutrients dynamics in and losses from watersheds.

For a watershed in the Rocky Mountains of northern Colorado, Lewis and Grant (1979) found that concentrations of bicarbonate, nitrate, calcium, magnesium, and sodium decreased with increasing stream discharge; concentrations of dissolved organic carbon, hydrogen ions, and phosphate increased with increasing discharge; while ammonium, dissolved organic phosphorus and nitrogen, potassium, and sulfate concentrations showed no trend of change with streamflows. In a related study, Lewis and Grant (1980) also found that decreased snowpack was associated with greater areas of frozen ground and significantly greater runoff of calcium, magnesium, potassium, phosphate, nitrate, dissolved organic phosphate, bicarbonate, and hydrogen ions. Sulfate, sodium, nitrate, ammonia, dissolved organic carbon, and dissolved organic nitrogen displayed no significant relationship to snowpack.

During their analysis of water quality in streams of the Fraser Experimental Forest in Colorado, Stottlemyer and Troendle (1987) found that major cation and bicarbonate concentrations were much greater than those reported by Lewis and Grant (1979, 1980). Stottlemyer and Troendle also found that trends of change for cations associated with stream discharges were similar to those reported by Lewis and Grant, but these patterns tended to be weaker and there was no significant change in anions with discharge. The differences were attributed to differences in watershed geologies, which led them to caution against making generalizations about "representative" watersheds, their functions, and their responses.

Material Spiralling in Streams

In flowing waters, nutrients, energy, and other materials tend to cycle from organisms to sediments to suspension and then back to organisms again at "progress intervals" downstream. This contrasts with nutrients cycles in lakes and terrestrial ecosystems where these cycles often are completed within relatively close spatial proximity of each other. Thus, in rivers and streams the continual downstream movement of these cycles has been termed "spiralling" (Webster and Patten 1979).

While travelling downstream, materials can be transferred among environmental compartments where nutrients can be "stored" for varying periods, effectively altering rates of downstream transport. Storage times for different compartments can be relatively long or short. For example, some nutrients incorporate mostly into tissues of organisms, from which they are released back into the water at relatively slow rates; other nutrients can be rapidly excreted by organisms into the water, where they are readily available for use by other organisms. Such differences produce spirals of different spatial lengths for different nutrients, different streams, or different reaches of the same stream (Newbold et al. 1981).

Under this concept, "tighter" nutrient spirals are associated with constancy in stream ecosystems, increased biomasses of resident biota, spatial heterogeneity through the stream continuum, resistance to external stresses, and ability for rapid recovery from perturbations. Disturbances tend to disrupt storage mechanisms, increase losses of dissolved nutrients and/or nutrients in the sediment, and increase spiral lengths within streams (Newbold et al. 1981, Webster and Patten 1979).

River Continuum Concept

Much of the current understanding about the total nutrient and energy dynamics in flowing water systems has been summarized and synthesized within the "River Continuum Concept," which describes changes

in structure and function through lengths of river systems (Minshall et al. 1983, 1985; Sedell et al. 1978; Statzner and Higler 1985; Vannote et al. 1980). Most simply this theory proposes that biological systems occupying natural, undisturbed river systems are shaped fundamentally by the physical forces present in watersheds. Progressive downstream changes in these physical characteristics are suggested to produce a continuum of change in sources of energy, sizes of organic (food) particles, and types of organisms.

Upstream, headwater reaches tend to be dominated by riparian vegetation, which reduces production of instream plants by shading and contributes large amounts of allochthonous materials to the system. These contributions cause carbon stores to be dominated by coarse particulate organic materials (Speaker et al. 1984). Consequently, invertebrate communities in headwater streams will tend to be dominated by organisms that shred coarse matter into fine particles, and by those that collect these drifting particles. Due to the preponderance of materials and energy originating from outside of the system, the instream ratio of community photosynthesis to respiration (P/R ratio) is generally less than 1, i.e., more carbon compounds are used by the community than are produced by it.

Downstream, in medium-sized streams, algae and other aquatic plants have greater importance. With the increase in autotrophic production, P/R ratios often can exceed 1. This shift in the energy base for these streams favors the dominance of invertebrates capable of collecting particles released by upstream processes, and of those able to graze on the plants growing in the streams.

Further downstream, the energetics of large rivers are increasingly dominated by fine particles released by upstream sources. Here the rivers again have P/R ratios of less than 1 and the invertebrate communities tend to be dominated by collectors.

Through the River Continuum Concept it is suggested that streams having low physical variability tend to have low biological diversities and high ecological stabilities. Alternatively, streams with high physical variability tend to have high biological diversities and complexities, while also tending to maintain ecological stabilities. Stabilities developed by biological communities in stream systems may be thought of as a strategy through which energy or nutrient loss downstream is minimized.

The River Continuum Concept was developed using research based largely on flowing water systems in the wet coniferous forest of the Northwest and in the deciduous and coniferous forests of the East and Midwest. Of course, patterns of riparian vegetation that differ from those generalized above can produce variations in the other inherent aspects of the adjacent stream (Conner and Naiman 1984, Gurtz et al. 1988, Minshall et al. 1985, Statzner and Higler 1985). Also, disturbances within stream systems can disrupt the overall stream continuum by changing conditions over the disturbed reach to conditions more similar to those occurring either upstream or downstream of the disturbance (Vannote et al. 1980, Ward and Stanford 1983). Little is known on how the streams and rivers of the central Rocky Mountains conform to or deviate from the River Continuum Concept.

Water Quality Criteria for Fish and Other Aquatic Life

Beyond the natural determinates of water quality, numerous cultural activities can alter the quality of surface waters and affect aquatic habitats, as are more fully detailed in later sections. For example, clearcuts or other watershed disturbances tend to increase the loss of ions (Dillon and Kirchner 1975; Prairie and Kalff 1988a, 1988b; Vitousek 1977). Various forest use activities can alter water qualities and potentially produce conditions that violate water quality criteria established by the U.S. EPA to protect fish and other aquatic life. This brief overview of the U.S. EPA's present water quality criteria for suspended sediment, temperature, pH, nutrients, and various additional potentially toxic chemicals is based largely on the "Quality Criteria for Water" produced by the U.S. EPA (1986) and on an earlier review completed by the American Fisheries Society (Thurston et al. 1979).

Suspended Sediment

The European Inland Fisheries Advisory Commission concluded that suspended sediment can affect aquatic organisms by killing them directly, by reducing growth rates and resistance to disease, by preventing successful development of eggs and larvae, by modifying natural movement or migration patterns, or by reducing the natural availabilities of food (U.S. EPA 1986). A review completed by the National Academy of Science suggested that a limit of 25 mg/L of suspended sediment would provide high, 80 mg/L moderate, 400 mg/L low, and over 400 mg/L very low levels of protection for aquatic organisms (Thruston et al. 1979). The present water quality criterion established by the EPA for fish and other aquatic life is based on the depth in the water column at which planktonic photosynthesis equals respiration; hence, it does not apply to most salmonid habitats in the central Rocky Mountains. Lloyd (1987) suggested, based on his review of turbidity studies in Alaska, that a water quality standard that permitted an increase of 25 NTUs (nephelometric turbidity units) above ambient would provide moderate protection for clear, coldwater stream habitats. It remains to be learned whether such a standard would be applicable to salmonid streams in the central Rocky Mountains.

Temperature

Most biological and chemical processes in aquatic environments ultimately are regulated by water temperature. Fish and essentially all other aquatic animals are cold blooded (poikilotherms); thus, their metabolism, reproduction, development, and scope for activity are largely controlled by environmental temperatures. Similarly, aquatic plant photosynthesis and respiration, chemical reaction rates, gas solubilities, and microbial mediated processes including decomposition and nutrient cycling are also temperature dependent. In fact, the

ederal Water Pollution Control Administration in 1967 escribed temperature as "a catalyst, a depressant, an ctivator, a restrictor, a stimulator, a controller, a killer, ne of the most important and influential water quality haracteristics to life in water" (U.S. EPA 1986).

The present criterion to protect freshwater aquatic life ; based on "the important sensitive species" resident uring the time of concern and consists of two upper temerature limits (U.S. EPA 1986). The first limit is based n short (i.e., over durations of minutes) exposure, is omputed using an equation presented in the EPA riterion, and uses data presented in a National Academy f Sciences document. The second limit is based on a veekly maximum average temperature, which changes vith season, with reproductive stage present, to mainin species diversities, or to prevent nuisance growths f organisms. For rainbow and brook trout adults and iveniles, the maximum weekly average temperature for rowth during the summer is listed as 19°C, and the hort-term maximum temperature limit for survival durng summer is 24°C (U.S. EPA 1986). This report also lists °C as the average weekly maximum temperature eported for spawning by these species, and 13°C as the hort-term maximum reported for survival of their mbryos. The present temperature criterion presents umerous interpretational problems with respect to efining "important sensitive species" and "short term" Thurston et al. 1979).

H

In natural waters, pH is primarily regulated by the soluon of atmospheric carbon dioxide, which reacts with vater to form carbonic acid and then disassociates to ydrogen and bicarbonate ions. Distilled water at quilibrium with atmospheric CO_2 has a pH of 5.6 at sea evel. But natural waters contain various dissolved salts nd organic chemicals derived from watershed rocks, oils, and organisms that tend to buffer the natural aciditeś and raise the pH of surface waters.

As with temperature, the concentration of hydrogen ons is an important regulator of many chemical and bioogical processes in aquatic environments. (Most ccurately, it is the chemical activity of hydrogen ions, ather than their concentration, that is reflected by measred pH levels.) For example, pH primarily defines the hemical natures of dissolved ions in waters, the direcions of chemical reactions, the adsorption of chemicals nto organic and inorganic particles, plus the availabilty and toxicity of chemicals to organisms. Similarly, ptake and release rates for ions across gills, the primary nethod of ion regulation for aquatic animals, is at least artly pH dependent. Environmental conditions beyond heir natural pH limits can produce stress and cause morality of organisms.

The criteria range to protect freshwater aquatic life is H 6.5 to 9.0 (U.S. EPA 1986). Many fish, however, are vell able to survive and reproduce at pH levels outside f this range. Also, not all species and not all life stages f most species are equally sensitive to pH changes. For example, as acidity levels increase, brook trout are generally less sensitive than brown trout, which are in turn less sensitive than rainbow trout; hatching and larval stages are the life stages for these species that are most sensitive to acidity (Marcus et al. 1986). Brook trout populations frequently have been found to inhabit waters that have pH levels less than pH 5.5 (e.g., Schofield and Trojnar 1980).

Nutrients

The two nutrients of greatest potential concern in aquatic systems are nitrate and phosphate. These nutrients are the two most related to the eutrophication of surface waters, the associated nuisance growths of algae, and the development of other noxious conditions. No criterion is provided by EPA for either of these two nutrients with respect to the control of eutrophication. The U.S. EPA (1986) does discuss the toxic potential for nitrates to fish. This report concludes that nitrate-nitrogen concentrations at or below 90 mg/L should be protective for warmwater fishes, while concentrations at or below 0.06 mg/L should be protective for salmonid fish. This guideline for salmonids is based on very limited data, and many natural salmonid waters have nitrate concentrations exceeding this level.

The U.S. EPA (1986) suggests as a guideline to prevent nuisance algal growths and limit cultural eutrophication that total phosphates as phosphorus should not exceed 0.1 mg/L in any stream or other flowing water, exceed 0.05 mg/L in any stream at the point where it enters a lake or reservoir, or exceed 0.025 mg/L in any lake or reservoir. In general, eutrophication may occur in surface waters that have nitrate-nitrogen concentrations above 0.3 mg/L and phosphate-phosphorus concentrations above 0.02 mg/L (Golterman 1975). Since algae on an average contain nitrogen and phosphorus in ratio of 16:1, this ratio in natural waters is commonly cited as an important indicator of relative nutrient limitations by these two nutrients (Stumm and Morgan 1970). Higher ratios indicate possible phosphorus limitation, while lower ratios indicate possible nitrogen limitation. Knowledge of this ratio for surface waters can help to target potential sources of nutrients and to guide corrective management actions aimed at reducing possible eutrophication problems.

Potentially Toxic Chemicals

Fisheries can be affected by an increasing diversity of potentially toxic chemicals. A review of the toxicity and potential impacts of all of these chemicals is beyond the scope of this report. But, table 2 lists the lowest observed effects levels obtained from short-term acute toxicity and long-term chronic toxicity tests for a variety of toxicants potentially encountered by salmonids in streams of the central Rocky Mountains; water concentrations less than the indicated levels may not affect fish. The reported levels are summarized from the U.S. EPA's 1986 water quality criteria, and provide a guideline to determine

Table 2.—1986 quality criteria for water (U.S. EPA 1986).

Chemical	Freshwater concentration in μg/L Acute criteria	Chronic criteria
Aldrin	3.0	
Ammonia	Criteria are pH and temperature dependent	
Antimony	9,000[1]	1,600[1]
Benzene	5,300[1]	5,100[1]
Beryllium	130[1]	5.3[1]
Cadmium	3.9[2]	1.1[2]
Chlordane	2.4	0.0043
Chlorine	19	11
Chloroform	28,900	1,240
Chromium (Hex)	16	11
Chromium (Tri)	1,700[2]	210[2]
Copper	18[2]	12[2]
Cyanide	22	5.2
DDT	1.1	0.0010
DDT metabolite (DDE)	1,050[1]	
DDT metabolite (TDE)	0.6[1]	
Dieldrin	2.5	0.0019
Endrin	0.18	0.0023
Iron		1,000
Lead	82[2]	3.2[2]
Malathion		0.1
Mercury	2.4	0.012
Nickel	1,800[2]	96[2]
Parathion		0.04
pH		6.5–9.0
Phenol	10,200[1]	2,560[1]
Selenium	260	35
Silver	4.1[2]	0.12
Sulfide-hydrogen sulfide		2
Thallium	1,400[1]	40[1]
Toluene	17,500[1]	
Zinc	320[2]	47

[1]*Insufficient data to develop criteria. Value presented is the Lowest Observed Effect Level (LOEL).*

[2]*Hardness dependent criteria (100 mg/L hardness level used for reported value).*

potentially hazardous conditions for salmonids in the central Rocky Mountains. For a specific water, actual toxic concentrations are often likely to be either greater or less than the reported values. For example, the toxicity of ammonia increases as either temperature or pH of the water increases (Thurston et al. 1979).

As another example, the toxicity of many metals and other chemicals is affected by hardness. That is, actual instream toxicities of metals to aquatic organisms does not depend solely on the total concentrations of the metals in the water. A variety of studies, including those from the Rocky Mountains, show that water quality characteristics, especially hardness, alkalinity, pH, and chelating organic materials, can affect the aquatic chemistries, toxicities, and bioavailabilities of metals (Black et al. 1975, Marcus et al. 1983, Parkhurst et al. 1984). Studies also reveal that not only can calcium hardness, in particular, affect the instream chemistry of many metals, but it can affect the physiological susceptibilities of the organisms to the potential toxicities of many metals (Davies and Woodling 1980, Mount et al. 1988, Parkhurst et al. 1984, Pascoe et al. 1986).

In addition, potentially toxic chemicals are rarely present singularly; toxicities derived from multiple chemical sources may be additive, subtractive, or mul- plicative. Therefore, when evaluating the potential to icities to fish by chemicals in surface waters, evaluatio must include careful determination of and potential inte actions with other chemicals present.

Instream Biological Relationships

Various interactions occur among fish and oth aquatic organisms inhabiting streams. These incluc competition for space and food resources, natural pr dation, and interactions with beaver.

Competition for Space and Food Resources

When resource demand exceeds resource availabilit fish species may adjust their use of those resources, i.e undergo niche shifts. Thus, competition may structu fish communities, depending on the ability of each sp cies to adapt to competition. However, Hearn (1987) note that factors limiting fish densities may reduce eliminate the impact of competition on fish commun ties. And one salmonid species may replace another b mechanisms other than competition (Robinson and Tas 1979). These include predation, disease, and habitat alte ations to the disadvantage of a species. Nonetheless, variety of experiments demonstrate niche shifts b salmonids that have been attributed to competitio (Hearn 1987); many of these species inhabit streams i the central Rocky Mountains.

Fausch and White (1981) noted that brown trout appa ently excluded brook trout from certain stream micr habitats; they concluded that brown trout occupied th most favorable feeding sites (those sites possessing lo velocity water adjacent to food-carrying high velocity cu rents). Habitat perturbation may exacerbate the adva tage of brown trout over brook trout (Waters 1983). Whe sympatric with brown trout, rainbow trout shifted t microhabitats with greater water velocities, over coars substrates, farther from overhead vegetation, and wit less shade than when allopatric (Gatz et al. 1987). Broo trout apparently displace cutthroat trout (Behnke an Zarn 1976), though Griffith (1972b) suggested that thes species prefer different habitats in allopatry and sym patry. Due to the interaction with rainbow trout, cutthroa trout in a British Columbia lake shifted from midwate areas when allopatric to littoral zones when sympatri (Nilsson and Northcote 1981). Finally, rainbow trout ten to replace brook trout, possibly due to competition fo food immediately after swim-up by larval rainbow trou (Rose 1986). Nonetheless, the existence of competitio between any of these species has not been directly veri fied in the central Rockies.

As fish grow, their microhabitat preferences may shif Everest and Chapman (1972) noted that age 1 steelhea occupied deeper, faster sites than did age 0 steelhead But greater size is also associated with dominance i salmonids (Newman 1956). Jenkins (1969) reported tha size strongly correlated with dominance among brow

ıd rainbow trout in two California streams. Therefore, different age classes of a single species prefer the same icrohabitat, the larger individuals should occupy the ost favorable sites and displace the smaller fish to boptimal sites (interactive habitat selection; Fretwell 72). Larger age 1 brown trout aggressively displaced unger brown trout from certain microhabitats (Symons ıd Heland 1978). Alternatively, Baltz and Moyle (1984) ggested that habitat use was related to developmental anges, not to dominance (selective habitat segregation). any case, the interaction between ontogenic shifts in icrohabitat preference and intraspecific competition is ot well understood.

Invertebrates serve as the primary food for many poputions of salmonids, though they occasionally act as edators on embryonic or juvenile salmonids (Claire and illips 1968). Though invertebrates may be captured om the substrate, salmonids generally feed in the water lumn (Elliott 1970). The presence of invertebrates in e water column of streams is known as *drift*. Invertete drift tends to peak shortly after dusk or during physal disturbances (e.g., floods), but drift persists continusly at low rates in most streams (Waters 1969).

Drift may be critical in determining microhabitat oice by salmonids. Chapman (1966) suggested that rritorial defense by salmonids is a substitute for ramble competition for food. Fausch (1984) compared sitions occupied by juvenile coho salmon that had rmed a dominance hierarchy, and found that the rankg of sites by potential net energy gain (energy from food ss energy for maintaining position in the water column) as positively correlated with the rank of fish in the minance hierarchy. Densities of rainbow trout fry in perimental channels peaked and aggressive behavior eclined at high drift densities, but densities decreased ıd aggression increased at low prey abundance (Slaney ıd Northcote 1974).

Sympatric salmonids frequently consume the same ods; the invertebrate diets of brown and rainbow trout lliott 1973), brown and brook trout (Allan 1978), and itthroat trout and coho salmon (Glova 1984) overlapped eatly. Griffith (1972a) reported that age 0 brook and cutroat trout consumed similar foods, but the diets of these ecies differed among older fish. Typically, the proporon of invertebrates in salmonid diets tends to reflect the oundance of aquatic and terrestrial invertebrates in the ift (Cada et al. 1987a, 1987b). But invertebrate predaon by salmonids is size-selective, i.e., the largest dividuals of invertebrate species are preferred (Allan 978, Dunbrack and Dill 1983, Newman and Waters 1984) ıd small salmonids tend to capture smaller prey than large salmonids (Glova 1984). Additionally, individual sh may specialize in capturing certain invertebrate spees despite the presence of more abundant invertebrates Dill 1983), or salmonids may avoid certain abundant vertebrates (Ringler 1985). Finally, salmonids may alter e abundance of various aquatic invertebrates; troutless ools in a California stream contained significantly more donate naiads, coleopteran larvae, and hemipteran dults than did pools containing trout (Hemphill and ooper 1984).

Predation

The impact of natural (nonfishing) predation on salmonid populations in the central Rockies is largely unknown. Bowlby and Roff (1986) noted that trout biomass was related to the presence of northern pike in southern Ontario streams, but the occurrence of this piscivorous (fish eating) fish accounted for very little of the variation in trout biomass. Burgess (1980) noted that mink fed little on trout but instead preferred crayfish. However, Alexander (1976) believed mink control would improve salmonid populations in Michigan streams. Squawfish (*Ptychocheilus lucius*) predation on migrating smolts is believed to be a significant source of salmonid mortality in the Columbia River (B.E. Rieman, Oregon Department of Fish & Wildlife, personal communication). Dippers (*Cinclus mexicanus*) appear to consume large numbers of recently emerged fry of Colorado River cutthroat trout in the North Fork Little Snake River drainage in Wyoming (M. Bozek, Department of Zoology and Physiology, University of Wyoming, personal communication). Nonetheless, despite the variety of birds, mammals, and fishes that are piscivorous, the magnitude of this predation has rarely been quantified.

Beaver-Trout Interactions

Beaver-trout relations in the United States have been studied since the 1940s (Huey and Wolfrum 1956, Patterson 1950, Rasmussen 1941, Rupp 1954). Several surveys of trout in beaver ponds in the central Rocky Mountains have been conducted (Call 1960, 1970; Gard and Seegrist 1972; McDowell 1975; Rabe 1970).

Since the early studies, a dichotomy appears to exist between beaver-trout relations found in the eastern United States versus the Rocky Mountains (Allen 1956). In the East, beaver impoundments are generally detrimental to trout populations due to their tendency to increase water temperatures above tolerance limits for the resident salmonids, to cover spawning gravels with silt, to remove bankside cover, and/or to entrap predators within the ponds. In the Rockies, however, beaver ponds generally appear to benefit salmonids. Increased water temperatures in the ponds is often correlated positively with trout growth, and siltation of spawning areas is generally precluded by greater stream gradients, which also prevents beavers from impounding the entire streamcourse (Retzer et al. 1956). Also, beaver ponds can enhance baseflows in streams. While removal of bankside vegetation by beaver tend to increase water temperatures in beaver ponds, this potential benefit relative to the negative impact from losing overhead cover for trout has not been quantified.

Despite the general benefits provided salmonids by beaver in the West, they can adversely affect trout in two ways. First, large numbers of dams over relatively short stream distances can prevent or slow the movement of spawners to suitable sites. During the spring, however, high water levels in the ponds and over sections of the dam probably mitigate this potential impact. Second,

siltation of spawning sites can occur in some western streams. While the extent of this siltation has been shown to be negligible under normal circumstances or over short time periods (Rasmussen 1941), dams are more prone to washout when built where erosion-resistant substrates or structures (e.g., rock outcrops and moraines) are lacking. Then, potentially large masses of previously trapped sediment can be released to cover downstream spawning gravels and limit spawning success.

In total, beaver ponds in the Rocky Mountain West tend to support greater production of aquatic invertebrates, as well as more and larger trout than undammed sections of the same stream (Huey and Wolfrum 1956, Naiman et al. 1984). This, however, depends somewhat on the age of the pond; often older ponds support large biomasses of stunted trout (Rabe 1970). Generally, invertebrate prey for salmonids in beaver ponds have greater densities and masses, apparently due to the higher alkalinities, warmer water temperatures, and greater productivities found in beaver ponds. Also, recent work has shown that beaver ponds can be a sink for nutrients from influent streams, which may further contribute to the increased productivity in these ponds (Maret et al. 1987).

Recently, a method has been devised that predicts trout abundance in beaver ponds by relating habitat attributes to trout abundance (Winkle 1988). The habitat variables most significantly correlated with trout productivities were surface area of the pond, mean depth, potential spawning habitats, downstream pond density, and spring to fall water level fluctuation. Additional study and validation of this model is required before it can be generally applied.

POTENTIAL IMPACTS TO SALMONID HABITATS

Cultural developments in forests can have severe consequences on trout habitats. These activities include road construction and use; logging and reforestation; fire; livestock grazing; water developments; mining and mine reclamation; recreation, including fishing, fish management, and fish stocking; and urbanization. These activities can affect salmonid habitats individually and cumulatively.

Impacts Associated with Roads

Roads built in forests can impact salmonids and their habitat primarily through two mechanisms. First, forest roads increase erosion rates and sediment loads in streams, potentially affecting salmonids by reducing respiration and ion exchange rates across gills and by clogging spawning areas. Second, improperly constructed road culverts and bridges can block migration routes. In addition, there is some evidence to suggest that road networks alone can accelerate peak flows in small watersheds because roads effectively increase drainage networks in watersheds (Chamberlin 1982); but, the importance of this potential impact to salmonids will not be discussed here.

Erosion and Sediment

Many studies have associated increased stream suspended solids and channel sedimentation load with roads (e.g., Cline et al. 1983, Fredriksen 1970, Krammes and Burns 1973, Yee and Roelofs 1980). In fact, roads can be the major source of sediment to forest streams (Packer 1966). These studies show that large releases of sediment have been associated with failures of cutbanks and fill slopes, road surface erosion, ditch erosion, and failure of drainage structures. Also, landslides, slump earth flows, and debris torrents are mass erosion events frequently associated with road construction (Everest et al. 1985a). A study in the Cascade Mountains found that landslides within road cut corridors were 27 times more frequent than the frequency of landslides in forested areas without roads (Lyons and Beschta 1983). Of course, landslide frequencies also largely depend on the nature of the underlying geologies and the grades of cut slopes in addition to the nature of the road (Duncan and Ward 1985). Debris torrents can leave deep accumulations of boulders, large woody debris that blocks fish passage, and fine sediment that clogs spawning and rearing habitats.

A study in steep-sloped forests in Idaho suggested that skyline logging alone (without the influence of roads) increased sediment erosion by a factor of about 0.6 over natural rates, while roads associated with jammer logging increase sediment production by over 750 times during the 6 years after road construction (Megahan and Kidd 1972). When roaded areas exceed 2% to 3% of the watershed, accumulations of sediment in the stream gravels can markedly increase. Paved roads released less that 1% of the sediment that was released from heavily used roads with gravel surfaces, and sediment production increased with the use intensity of roads (Reid and Dunne 1984). Heavy use (greater than four loaded logging trucks per day) increased sediment production 750% over that occurring when the roads were not used; occasional use by light vehicles limited sediment loss to less than 1% that occurring with heavy use. Effects of forest roads on watersheds in mountainous areas are reviewed by Megahan (1985, 1987).

Approaches to control erosion on forest roads have been presented by Everest et al. (1985a), Kochenderfer (1970), Megahan (1985, 1987), and Yee and Roelofs (1980). Both Leaf (1974) and Reid and Dunne (1984) present methods to estimate sediment production from forest roads. Briefly, sediment impacts due to roads can be at least partly mitigated to protect salmonid habitats by careful planning of their location and design, use of lower impact construction methods, and, because deteriorating roads can contribute greatly to instream sediment loads, establishing programs of regular road maintenance.

Culverts and Fish Passage

Culvert and bridge placement can cause loss of habitat at least through the reach of the placement, plus through any area above and below that is necessary to stabilize the structure. Road culverts can also produce serious

otential threats to fish migration because of outfall barers, excessive or insufficient flows through culverts, lack f resting or jump pools, or a combination of these facrs (Evans and Johnston 1980, Everest et al. 1985a, Yee nd Roelofs 1980). The resulting blockage can cause loss f important spawning or rearing habitats in streams oove improperly designed and installed bridges and ılverts.

Because bridges generally disturb the stream less than ılverts, construction of bridges is often preferable to ıstallation of culverts, but often culverts are more ecoomical. Yee and Roelofs (1980) suggest a diversity of onsiderations necessary to minimize potential effects of orest road culverts on salmonids. These include (1) establshment of a resting pool immediately below the culert that permits fish to conserve energy and obtain a ood start to overcome the obstacle; (2) minimizing the ımp necessary to enter the culvert to generally less than foot, or to less than 0.5 foot if a series of jumps is equired; (3) if swimming distances through culverts or ridge aprons are greater than 50 to 100 feet, resting pools ıay be required en route; and (4) a second resting area ıould be available upstream. Finally, culverts are best laced where there are no sudden increases in water elocities above, through, or below culverts; where the ream alignments are similar above and below the culert; and where the culvert can be installed as close to a ero gradient as possible. Additional approaches to mitiate the effects of road construction have been suggested y the AFS Riparian Habitat Committee (American Fishries Society 1982), and an annotated bibliography of terature associated with fish passage and road crossings as been prepared by Anderson and Bryant (1980).

Impacts Associated with Forest Harvest and Reforestation Practices

In addition to impacts directly associated with road onstruction, forest harvest and reforestation practices an also affect salmonid habitats by altering patterns for rosion and deposition of sediment, streamflows, fish ıigrations, structural habitat cover, water temperatures, utrient cycles, and potentials for exposure to toxicants. almonid populations naturally encounter fluctuations ı many of these patterns, and they have evolved natural rategies to compensate for such environmental changes. ut the magnitude and frequency of such changes often ıcrease under timber management activities. This can roduce excessive stress on resident salmonid populaons and lead to long-term population declines.

Several comprehensive reviews are available that disuss the effects of forest management and forest use on shery habitats. For example, Brown (1974) examined how ıultiple use affects the hydrologic cycle and water qualy in forest streams. Chamberlin (1982) overviewed the ffects of timber harvesting on stream ecosystems, while verest and Harr (1982) reassessed the effects of silviculıral treatments. Everest (1984) compiled a list of sugested guidelines for coordinating wildlife and fishery abitat concerns with forest management activities. And, Everest et al. (1985a) recently reviewed the effects of timber management activities on salmonid habitat. Because such recently completed comprehensive reviews exist, we will only highlight some of the more important relationships. In general, most timber management activities, including harvest schedule, cutting systems, felling, yarding, and other silvicultural activities, have considerably less impact on fisheries habitat than do roads (Everest et al. 1985a).

It is important to emphasize, however, that most of the information available on the relationships between timber harvest and salmonid habitats has been obtained from studies focusing on anadromous fish species in forests of the Pacific Northwest. Little published information is available that relates forest harvest and reforestation directly to salmonid habitats in the central Rocky Mountains. Accordingly, the relationships discussed in the following paragraphs require, for the most part, additional study to evaluate their significance for salmonid habitats in the central Rocky Mountains.

Erosion and Deposition of Sediment

Sediment production from watersheds can increase dramatically when old-growth forests are logged. In fact, sediment levels in streams are likely to establish new equilibria above base levels that will remain as long as the watershed is intensively managed for timber (Everest et al. 1985a). The extent of the sediment related impact, however, is directly related to precipitation input volumes.

Logging can reduce the stability of slopes and cause mass erosion events (e.g., landslides, debris torrents), providing temporary or long-term barriers to migration (Everest et al. 1985a). One study in the Cascade Mountains found that landslides associated with clearcuts were 23 times more frequent than in forested areas (Lyons and Beschta 1983). When the slopes are near the limit of their safety factor, timber harvesting can accelerate rates of mass movement, especially in response to large storms and other major events. The extent or rate of mass movement, however, is hard to predict. If these events occur near or in stream channels, the impacts can be substantial. Recovery of slopes from mass movement and the impacts of their sediment on streams can continue for several decades (Chamberlin 1982). To avoid such impacts, managers must identify and avoid harvesting timber on slopes above or near stability margins (Chamberlin 1982).

When logging removes riparian vegetation, the stability of streambanks is decreased. This can substantially decrease the buffering effect produced by riparian vegetation and increase sediment delivery to streams (Everest et al. 1985a). This also can lead to stream channels becoming wide, shallow, and unstable, often with braided channels. As pools and gravels fill with sediment, they become less suitable habitat for trout. In small streams, channel aggradation produced by accelerated erosion can produce underground flows through deeper gravel layers during the summer and block migration

routes. Barton et al. (1985) demonstrated the importance of buffer strips to trout in small Ontario streams.

Harvest techniques producing large bare areas, including tractor yarding and skidding, and harvest schedules that allow entire watersheds to be cut within a few years, can increase sediment production sufficiently to degrade salmonid habitat (Everest et al. 1985a). But felling has little effect on salmonid habitat, unless timber is felled directly into streams. Cable yarding and skyline systems produce little effect if riparian and floodplain areas are not damaged.

Various techniques can be used to reduce logging remnants and ready sites for reforestation. These include broadcast burning, brush raking or blading to pile slash and remove brush, and ripping compacted soils under landings and roads. The potential for erosion from these areas is directly proportional to the amount of soil exposed, extent of soil disturbance, slope gradient, precipitation input, stability of the exposed soil aggregates, and the proximity of the site to a stream (Everest and Harr 1982). Ripping compacted areas can actually reduce the long-term potential for erosion by enhancing conditions that speed revegetation (Everest and Harr 1982).

Despite the potential for substantially increased erosion as a consequence of logging, timber harvest operations in mixed conifer forests do not markedly increase erosion rates if the timber operation is done professionally (Heede 1987). Everest et al. (1985a) presented a number of management considerations that can help to minimize soil erosion. Briefly, these include approaches to minimize soil disturbances during logging and measures that can help to avoid impacting stream channels and riparian areas directly. Megahan and King (1985) also presented important considerations for identifying critical areas of forests for control of nonpoint sources of sediments.

Streamflow Alterations

Various studies in small, experimental watersheds have shown that logging can increase streamflows in both the Rocky and the Cascade Mountains, with the degree of increase dependent on characteristics of the harvest in relationship to the watershed topography and wind patterns (e.g., Harr et al. 1979; Leaf 1975a, 1975b; Troendle 1980; Troendle and King 1987). But other studies in both areas indicate that timber removal can result in no increase or even a decrease in seasonal runoff volumes, and that annual changes in runoff volumes may be associated more with annual differences in precipitation than with the percentages of forest harvested (Fowler et al. 1987, Harr 1980, Johnston 1984, Troendle and King 1985). Similarly, while various studies show that logging can increase flows from the small, experimental tributary subdrainages, these increases often appear to produce relatively minor changes in the main channels downstream (Harr et al. 1979, Troendle and King 1987). Indeed, the effects of operational logging on water flows from larger watersheds or regionally are unclear (Chamberlin 1982, Ziemer 1987). In general, however, it appears that vegetation management options will have little relationship with streamflows where precipitation is less that 5 inches per year, and some, but minimal, effect where they are less than 20 inches per year (Ziemer 1987).

The experimental studies show that small harvest openings (up to 8 tree heights) often appear to be more effective at trapping snow (Chamberlin 1982; Leaf 1975a, b). Due to this and to reduced evapotransporation because of the removed forest canopy, soils under logged forests tend to be more saturated with water in the spring. Consequently, runoff volumes tend to occur earlier in the spring (by as much as 1 month) and in greater volume. In the central Rocky Mountains, this phenomenon can persist without lessening for up to 20 years, and can continue for at least 50 years (Chamberlin 1982, Troendle 1980). The extent and duration of the modification in runoff patterns depend on the distributions of the cuts and their aspects, elevations, and distances from stream channels. It may be possible to manage these features of forest cuts to manipulate the delivery of water to stream channels for fisheries (Chamberlin 1982).

The amount of increase in spring runoff due to most timber cutting does not generally appear great enough to cause abnormal increases in streambed scouring. There is circumstantial evidence, however, that some streambed deterioration can occur when rain-on-snow events occur, or when very large percentages or entire watersheds are cut (Chamberlin 1982).

There is a prevailing belief that logging will benefit soils and water resources by desynchronizing the runoff from subcatchments; but, while timber removal can desynchronize subcatchment flows, it can, with equal likelihood, cause synchronization of previously desynchronized flows (Harr 1987). Whether such synchronization or desynchronization actually benefits salmonids and their habitats appears to depend on the specific watershed under discussion.

Alterations in Structural Habitats

Logging can leave large accumulations of large organic debris in streams (e.g., Duncan and Brusven 1985a). While this woody debris often can have a positive effect on salmonid habitat (e.g., rootwads can trap gravel, stabilize channel spawning areas, and create resting pools and cover), these accumulations also can provide temporary or long-term barriers to migration. Additionally, accumulations of logging slash can clog spawning gravels with fine organic particles, scour channels and cause instability during high flows, and cause routing and redeposition of gravels around debris accumulations (Everest et al. 1985a, Lisle 1986a). Finally, logging slash can also impede fishing access and other recreational opportunities (Chamberlin 1982).

As a consequence of debris torrents associated with accumulations of logging slash, numbers and biomasses of fish have been observed to be reduced by up to 90% in smaller streams and up to 50% in large streams, with little recovery occurring after 3 years (Everest and Meehan 1981a). Debris torrents also can degrade spawning

abitats by increasing the percentage of fine sediments y over 90% in spawning gravels and cause at least temorary declines in densities and biomasses of aquatic ıvertebrates. But debris torrents also have been found ɔ improve habitats for salmonids by creating new restıg pools and new deposits of spawning gravels (Everest nd Meehan 1981a).

Riparian vegetation removal, canopy removal, and xcessive stream cleanup can reduce the amount of large voody material entering streams, reducing the structural omplexity in the stream. Streams with varied channel ıorphologies, stable instream debris, and a variety of ubstrate sizes provide better cover for fish (Binns and iserman 1979). The presence of large woody debris reruited from riparian vegetation tends to create a series f check dams and plunge pools, which helps to collect ediment and provide protective cover for fish (Everest t al. 1985a, Lisle 1986a, Tschaplinski and Hartman 1983).

Harvest of large-diameter, old-growth forests predictbly yields small-diameter second-growth. Little is nown on how the resulting smaller sized logs entering treams will affect stream dynamics. Rates of sediment ansport may increase, producing streambeds that are ess stable and less productive over extended reaches Everest et al. 1985a).

Clearcutting to the edge of streams can produce unstale streambanks that collapse during periods of high treamflows and decrease the suitability of the habitat or salmonids (Tschaplinski and Hartman 1983). Buffer trips riparian vegetation left along streambanks can subtantially lessen logging impacts on streams by stabiliztg banks and helping to maintain or increase debris nportant to salmonid winter habitat needs (Murphy et l. 1986).

Newbold et al. (1980) found that buffer zones also can ave major influences on invertebrate populations imporınt as food for fish. In comparisons to stream samples om uncut forested sites in northern California, benthic ıvertebrate samples from commercially logged stream ites had dissimilar compositions; had lower taxonomic iversities; and showed higher densities for total macroıvertebrate fauna, *Chironomidae*, *Baetis*, and *Nemoura*. ı comparison, where streams in timber cuts had buffer trips greater than 30 m, the compositions and diversies of the benthic invertebrate communities were simiır to those in uncut forest streams. (There are no simiır studies on the effectiveness of buffer strips in the entral Rocky Mountains.)

Decisions that can benefit fisheries habitats during eforestation include selection of suitable vegetation and ppropriate planting distributions along the streams Everest and Harr 1982). Planting conifers instead of eciduous species can reduce the contribution of allochıonous organic materials to streams and reduce almonid productivities. When compared with closed anopies, open and semiopen stream reaches often are ıore productive. Research has shown that stream prouctivities may be enhanced by maintaining open treamside conditions, as long as solar heating does not ecome a problem. Where heating of the stream was a otential problem, plants of fast-growing species helped to lessen the problem. Also, reforestation programs that included long-term plans for the recruitment of large woody debris to streams can enhance salmonid habitats (Everest et al. 1985a).

Alterations in Water Temperatures and Incident Light

Removal of the riparian canopy adjacent to and within riparian zones produces an increase in summer temperatures and a decrease in winter temperatures. The extent of temperature change appears to increase as stream sizes become smaller, gradients less, and time after harvest shorter (Chamberlin 1982, Murphy and Hall 1981). Rarely does canopy removal cause onsite increases in stream temperatures that are lethal to trout, but the sublethal and downstream cumulative effects can produce physiological and recruitment stress, and substantial deterioration in trout populations (Everest et al. 1985a, Levno and Rothacher 1967, Patton 1973). Elevated stream temperatures can at times block fish migrations.

Increases in water temperatures and in incident light levels within the canopy opening also can increase photosynthesis and productivity by algae in streams (Chamberlin 1982, Duncan and Brusven 1985c, Murphy et al. 1986). This can shift the energetic bases of the affected streams to increasing contributions by autochthonous sources (Everest and Harr 1982). In turn, this can increase the densities of invertebrate food items for fish. The increased water temperatures associated with opening of the canopy can also extend the growing season and increase the growth rate for fish (Holtby 1988).

Various studies have shown that flora and fauna are often more abundant in stream sections with open forest canopies (Everest et al. 1985a). For example in the Cascade Mountains of Oregon, Murphy and Hall (1981) found generally greater biomasses, densities, and species richnesses of both fish and insect predators in clearcut sections where the stream was still exposed to sunlight 5 to 17 years following logging as compared with old-growth (>450-year-old) stream sections. In a related study, Wilzbach et al. (1986) suggested that growth rates of cutthroat trout in logged sections relative to forested sections increased as a consequence of the higher invertebrate productivities and, consequently, higher invertebrate drift rates and foraging successes in the opened stream sections. Johnson et al. (1986) found for southern Alaska streams that summer densities and growths of juvenile steelhead were greatest in clearcut sections relative to forested sections or sections with streamside buffer zones; during the winter, densities decreased by over 90% in the clearcut sections, but increased by 100% and 400% in the forested and buffered sections, respectively. Opening the canopy, however, can produce light or temperature conditions that can be damaging to some species (Everst et al. 1985).

It may be possible to regulate stream temperatures by judiciously designing a streamside harvest and revegetation plan to optimize light and solar heating of streams (Chamberlin 1982). With increased stream primary

productivities and stream temperatures, increased fish productivities may result.

Alterations in Water Chemistries

Concentrations of nutrients (e.g., nitrate, calcium, and potassium) in streams generally increase following logging activities (Bowden and Bormann 1986, Chamberlin 1982, Hornbeck et al. 1975, Likens et al. 1977, Schillinger and Stuart 1978, Vitousek and Matson 1984). This results from both decreased uptake of nutrients because of the removal of plants, and increased decay of the remaining dead plant debris. The effects on fish spawning and rearing activities are usually not detectable (Everest et al. 1985a).

Accumulations of fine particulate organic materials accompanying slash can increase the biological oxygen demand (BOD) as this material decomposes, and cause dissolved oxygen levels in the stream or sediment to be depleted below concentrations necessary for survival of incubating eggs (Chamberlin 1982, Everest et al. 1985a). Accumulations of fine debris in spawning gravels associated with debris torrents can lead to decreased dissolved oxygen in the gravels, due both to reduced water permeability through the gravels and to decomposition of the fine organic materials entrained in the gravels (Everest and Meehan 1981a).

Fertilizers, fire retardants, herbicides, and insecticides can be used to protect or enhance forest resources. Salmonids can be affected directly through physiological changes produced by these forest chemicals or indirectly through changes in their habitat conditions. Forest fertilization appears to be used primarily in the Pacific Northwest to lessen nitrogen deficiencies, but even in this region only relatively small portions of all forests are actually fertilized (Norris et al. 1983b). Stay et al. (1978, 1979) investigated the additions of nitrogen compounds to Cascade forests. They found that the fertilization resulted in no prolonged increase in stream nitrogen levels. Breach of buffer strips along streams did, however, result in temporary increases in stream nitrogen concentrations following fertilization. The temporary increases in stream nitrogen were followed by temporary increases in primary productivity by stream periphyton, but this was not accompanied by concurrent increases in stream invertebrate populations that could be conclusively linked to the fertilization. And fish assays showed no mortality associated with the fertilizer applications.

Early fire retardants were borate salts, which were effective and long lasting but were also potent soil sterilants that inhibited revegetation (Norris et al. 1983b). Subsequently, bentonite clay suspensions in water were used, but they proved to have relatively low effectiveness. Most commonly used retardants today contain primarily ammonium phosphate or ammonium sulfate, plus several other minor ingredients (Norris et al. 1983b). Such compounds have known potential toxicities to salmonids, and their direct applications to streams can lead to mortality; little is known, however, about the actual exposure risk to salmonids when these materials are applied outside of streams (Norris et al. 1983b).

The direct chemical effects as well as the behavior and toxicity of commonly used forest insecticides and herbicides have been reviewed by Norris et al. (1983). This review included 2,4-D (PGBE ester), picloram, atrazine, MSMA, forsamine ammonium, glyphosate, dioseb, malathion, carbaryl, azinphos-methyl, carbofuran, and acephate. They concluded that under typical operational use of these pesticides, only dioseb and malathion presented high potential for impacting fish (see also Woodward 197[illegible]).

In total, use of fertilizers, fire retardants, herbicides and insecticides in forest management generally have little effect on salmonids and their habitats, if direct application to the waters is avoided (Everest et al. 1985a, Norris et al. 1983b).

Impacts Associated with Fire

Forest fires affect salmonid habitat predominately by increasing erosion and deposition rates of sediments; other potential effects of generally less importance include releasing nutrients, increasing water temperatures by removing streamside shade, and increasing summer base flows (Everest and Harr 1982, Tiedemann et al. 1979). The actual nature of the impacts largely depends on the characteristics of the burn, the site's physiography, its soils, climate, and, subsequently, the postburn recovery by the vegetation. Fire does often increase runoff from the burn areas (Albin 1979, Everest and Harr 1982, Helvey 1980, Tiedemann et al. 1979).

The extent that burning impacts soils and, consequently, erosion and salmonid habitat depends on the degree of soil heating, which in turn depends on the (1) types and amounts of fuels present, (2) intensity of the burn, (3) soil moisture content, (4) nature of the soil litter, and (5) and soil composition (Everest and Harr 1982, Tiedemann et al. 1979). Typically, 8% of the heat from a broadcast burn is absorbed by soils, while 92% enters the atmosphere. With water present, soil temperatures will not exceed 100°C until after all soil water evaporates (Everest and Harr 1982). Destruction of soil organic matter, which helps to bind soil particles together, will tend to increase potentials for surface erosion, nutrient loss, and effects to salmonids. Lowest strengths of aggregation and highest potentials for erosion tend to relate directly with increasing quartz contents in the parent materials (Everest and Harr 1982). In contrast, soils derived from parent materials that can form clays, including basalts, andesites, and gabbro-containing materials, tend to support high plant productivities, contain higher contents of organic materials, and have low erosion potentials. With very intense burns, such as occurred at some locations during the 1988 Yellowstone fires, soils can become hydrophobic due to the movement of polar substances from the litter into the soil; formation of hydrophobic soil can slow rates for revegetation and lengthen times of postburn erosion (DeBano and Rice 1973; Savage 1974; [illegible] Swanson, Shoshone National Forest, Cody, Wyoming, personal communication).

Burns can cause release of chemicals, including nitro-en, phosphorus, sulfur, and other nutrients, when soil emperatures exceed their temperatures of volatility (Ever-st and Harr 1982). Other nutrients can be lost following re via leaching and soil erosion. Such nutrient losses an retard recolonization by terrestrial vegetation and pro-ong sediment losses to streams (Tiedemann et al. 1979).

Stream temperatures can increase directly as a result f the burn and indirectly as a result of opening the anopy cover. Early observations on increased stream tem-eratures due to direct heating by fires in Yellowstone ational Park found the fires did not impact resident almonid populations (Albin 1979). Subsequently, the ore intense fires in and around this park in 1988 were ound to produce direct mortality of resident salmonids; e heat from some of these fires was great enough to split ocks on stream bottoms (R. Swanson, personal ommunication).

The extent of postburn temperature increase related to anopy removal depends on latitude, elevation, cloud-ess, and the relative importance of groundwater contri-utions (Everest and Harr 1982). Some of the temperature icrease may be mitigated by increased stream discharges ollowing the burns, but the degree of this increase epends on the extent of the vegetation destroyed and, onsequently, the decrease in transpiration.

In general, forest burns appear to have little impact on ream nutrient concentrations. While relatively slight icreases in stream concentrations for some nutrients (e.g., alcium, magnesium, potassium, chloride, sulfate, phos-hate, and total organic carbon) have been associated with unoff from burn areas, no harmful effects on water qual-y have been observed for the burning of slash, prescribed urns, or for wildfires in Yellowstone, the Pacific North-est, or the Atlantic and Gulf Southeast (Albin 1979, verest and Harr 1982, Richter et al. 1982, Tiedemann et l. 1979). Similarly, changes in water qualities associated ith forest fires also have not been found to adversely ffect benthic invertebrate populations (Tiedemann et al. 979). Nutrient changes associated with forest fires will kely have little impact on salmonid habitats. Only when ogging residues were burned directly in the streams were ignificant increases in concentration of nutrients and oxic metals observed (Everest and Harr 1982).

In conclusion, existing evidence suggests that except for otentially serious effects by increased sediment impacts, ost forest fires will minimally impact streams and almonid habitats. The potential severity of any fire-related npact will increase, however, as the severity of the fire ncreases; total destruction of the surrounding forests and parian zones can produce dramatic and long-lasting egative impacts on aquatic habitats. Unfortunately, little ocumentation exists on the consequences of large fires n either short-term or long-term changes in water quali-es or salmonid habitat quality.

Impacts of Grazing

Haugen (1985) summarized the position of the Amer-can Fisheries Society: "Livestock grazing is one of the multiple uses of the riparian area rangelands; however, years of improper grazing is one of the major reasons why so much of North America's public and private riparian area rangelands are in poor condition." He also stated the society's request "that land managers develop best management practices for managing riparian areas, and update these practices as new research and management information becomes available."

Livestock grazing produces a variety of changes in the riparian zone and stream channel that may be detrimen-tal to salmonids. Platts and Raleigh (1984) presented the following categories:

1. Increased stream temperature due to loss of over-hanging vegetation
2. Increased sedimentation from bank and upland erosion
3. Increased coliform bacteria counts (though Gary et al. (1983) and Johnson et al. (1978) noted this was unlikely to harm salmonid populations)
4. Increased channel width due to hoof-induced bank sloughing and consequent erosion
5. Channel alteration
6. Plant community alteration and/or vegetation loss
7. Loss of riparian vegetation due to channel degra-dation and lowering of the water table
8. Stream channel trenching or braiding and conse-quent shift to more xeric species in the riparian zone.

Blackburn (1984) suggested that the removal of vege-tation by grazing could lead to increased raindrop impact, decreased soil organic matter, increased surface crusts, decreased infiltration rates, and/or increased ero-sion. Other impacts are reviewed by Kauffman and Krue-ger (1984), Meehan and Platts (1978), and Skovlin (1984).

When comparing heavily grazed streams with lightly grazed or ungrazed streams, the former were generally shallower, wider, and had less overhanging vegetation (Hubert et al. 1985; Platts and Nelson 1985a, 1985b; Stuber 1985). Trout populations often increased in re-sponse to reduced or no grazing (Prichard and Upham 1986, Stuber 1985). Platts and Rinne (1985) cited 16 studies demonstrating benefits to the riparian zone from eliminating grazing; trout populations had also increased in 12 of these studies. However, Platts and Nelson (1985a, 1985b) reported that the trout population did not increase in a grazing exclosure despite improvements in the ripar-ian zone, and speculated this was due to water quality degradation caused by grazing upstream from the exclosure. And trout populations may not respond as rapidly to reduced grazing as riparian vegetation (Hubert et al. 1985, Platts and Nelson 1985b).

Successful management of salmonid fisheries on grazed ranges remains a difficult problem. Platts (1981a) and Skovlin (1984) concluded that no existing range management strategies were compatible with improving or protecting riparian vegetation. Complete exclusion of grazing by fencing riparian zones is expensive and con-troversial (Platts and Wagstaff 1984). But Platts and Rinne (1985) contended that riparian zones recover relatively quickly, and that undercut banks, important for use by

salmonids as cover, may form. Additionally, Stabler (1983, 1985) reported that some formerly intermittent streams became perennial within fenced exclosures. He hypothesized this was due to vegetative regrowth, channel aggradation, and reduced soil compaction that led to increased infiltration rates and storage capacity.

Recent research indicates that some grazing strategies may be compatible with protecting riparian areas. Platts (1986a, 1986b) suggested that creating a separate riparian pasture or grazing during winter reduced livestock impacts. Bank damage by cattle and soil moisture have been linked (Marlow and Pogacnik 1985), thus grazing when soil moisture is less than 10% may prevent damage. Rest-rotation grazing or sheep grazing may be less deleterious than other livestock use (Platts 1986a). Nonetheless, rest-rotation grazing can overuse riparian zones if not aggressively managed (Platts and Nelson 1985a), and the benefits of sheep grazing are lost if the animals are allowed to concentrate in the riparian zone (Platts 1981a). In some circumstances grazing might be beneficial to salmonids; to reduce the sediment yield of highly incised streams with sheer banks, Siekert et al. (1985) suggested that summer or fall grazing could round these channels, and that such alteration would reduce sediment transport to streams containing salmonids.

Impacts of Water Development Projects on Streams

Reservoirs and diversion dams disrupt the natural continuum of streams by converting previous flowing water environments into standing water environments (Ward and Sanford 1983). Dams can block migration routes for resident stream organisms, alter flow regimes, and change temperature and nutrient patterns in downstream flows.

Over the impounded stretch of stream, many of those species most adapted to life in flowing waters are displaced by other organisms better adapted to life in standing waters. Concurrently, management problems change from managing stream species to managing reservoir species. Further consideration of these problems is beyond the scope of this review, but they have been previously discussed in depth (American Fisheries Society 1967, Hall 1971, Hall and Van Den Avyle 1986, Marcus 1987, Petts 1984).

Alterations in Flows Below Reservoirs

Natural daily and seasonal streamflow patterns can be dramatically altered downstream of reservoirs. With most reservoirs built for water supply and flood control, maximum spring streamflows are stored and minimum summer flows are augmented. In comparison with natural flow regimes, maximum flows downstream from such reservoirs are often markedly reduced, while summer minimum flows can be greatly enhanced. With diversion dams, downstream flows can be depleted during any season. Downstream of hydroelectric reservoirs, both the frequency and magnitude of daily flow fluctuations can be magnified greatly above the natural regimes. The abnormal fluctuations in daily and seasonal flow patterns created below reservoirs can lead to low-flow dewatering of spawning beds, and both low-flow and high-flow induced spawning interference, incubation mortality, and rearing mortality in resident fish (Fraley et al. 1986, Jacobs et al. 1987, Nelson 1986). Similar relationships also occur in invertebrate populations (Gislason 1985).

Downstream dewatering and desiccation are undoubtedly the worst of the possible adverse impacts on the stream and riparian habitats resulting from stream impoundment. For example, one study of the potential cumulative effects from microhydroelectric facilities in the Swan River drainage in northwestern Montana indicated that the associated dewatering could eliminate 23%, 19%, and 6% of the high quality rearing habitat for cutthroat, bull, and brook trout, respectively (Leathe and Graham 1983). Also, 20% of the known redds for bull trout would lie in dewatered reaches, which could significantly reduce this fishery.

Downstream Streambed Dynamics and Flushing Flows

In general, masses of sediment released downstream during construction of dams may be increased by more than 50% over historical sediment loadings (Petts 1984). The Montana microhydroelectric study further indicated that a significant negative correlation existed between juvenile bull trout densities and the amount of fine sediment in the streambed. Therefore, the authors projected that increased sediment delivered to the streams during construction of these facilities could significantly reduce this fishery (Leathe and Graham 1983).

Reservoirs and diversion dams disperse and disrupt flows and the kinetic energy patterns downstream. With this dispersal of energy, virtually all sediment carried by stream inflows settle to the reservoir bottom, causing aggradation (lifting of the river valley) upstream of the dams (Heede 1980, Newbury 1985, Petts 1984, Simons 1979). Consequently, waters discharged from reservoirs tend to be nearly devoid of suspended inorganic particles (Neel 1963, Petts 1984).

Alterations in downstream flows also redistribute the historical downstream supply of kinetic energy. In turn, this redistribution can substantially alter the morphology of the downstream channel as it accommodates the new energy regime in the regulated stream. In effect, a new "dynamic equilibrium" is created between the stream channel and the regulated flows (Heede 1980, Petts 1984). In most cases, however, a new equilibrium cannot be reached over the relatively short economic life (ca. 60 years) of most North American water projects, and instabilities in the downstream environments persist. Where instabilities cannot be controlled, major shifts to new streambed geometries occur.

Various instream forces contribute to changing the geometries of downstream channels. "Sediment-hungry" waters discharged from reservoirs rapidly entrain sediment to achieve equilibrium loads, degrading streambeds

and eroding river banks (Heede 1980, Simons 1979). If uncontrolled, the degradation and erosion can endanger downstream structures, including bridges and roads. The extent of streambed degradation, however, is limited by the extent of bed armoring, which is a layer of cobble or rubble too large to be moved by the existing hydraulic conditions and which, in turn, protects finer particles that accumulate below the armor layer (Simons 1979). With this protection, potentially greater sediment masses erode from streambanks, decreasing bank stability and often destroying riparian vegetation. Following destruction of the streambanks, downstream sediment loads can further alter the downstream geometry of the stream (Petts 1984).

Beyond these problems, stream regulation can lead to clogging of the bed gravels with fine sediment. In unregulated streams, natural peak flows during seasonal or storm-related runoff events mix the upper streambed layers and flush accumulated fine sediment from the deeper layers. But in regulated streams where natural peak flushing flows are greatly reduced, fine sediment can accumulate in the deeper layers, clogging the free flow of water (R.W. Nelson et al. 1987; Reiser et al. 1985, 1987). This can adversely impact the intragravel habitat important to the survival of benthic insects, incubating eggs, and rearing larvae. Considering the biology of regulated streams, flushing flow releases from reservoirs are needed whenever sediment accumulations begin to adversely affect aquatic habitats and interfere with life functions of the resident organisms.

Numerous methods are available to measure accumulations and changes in accumulations of fine sediment within streambeds (Reiser et al. 1985, 1987; Wesche et al. 1977, 1985b, 1987c). Reiser et al. (1985, 1987) evaluated their usefulness. While many are good, no method or group of methods presently stand out as the best approach. Similarly, at least 15 potentially useful methods exist to determine magnitude, timing, and duration of flows necessary to flush deep sediment from streambeds, but again no method is clearly superior. One of the simplest approaches is the Tennant (1975) method, which is the most common method used in the western United States. Under this method an adequate flushing flow is defined as 200% of the average annual flow. However, no recommended duration for an adequate flushing flow is provided by this technique; many state resource agencies recommend a period of 14 days.

An alternative approach has been applied in Wyoming by Wesche et al. (1977). Using information from the literature plus their own field data and observations, they recommended that bankfull flows needed to be maintained for 3 days to obtain adequate flushing of sediment. Subsequent to their recommendations, natural precipitation produced a series of 3 flushing flows that met or exceeded the magnitude and duration prescribed. Analysis of the sediment content in the streambed prior to and following these events indicated that the recommended flushing flows were ''somewhat successful'' in removing the deposited sediment (Wesche et al. 1985b, 1987c).

While flushing flows can require high flow rates to remove sediment from deep deposits in some streambeds, these high flow rates sometimes can be very stressful and damaging to biota resident in the stream channel. Also, not all streams develop clogged beds as a result of stream regulation. For example, if large sediment sources, particularly those with large deposits of silt and clays, are lacking within the watershed, flushing flows may be unnecessary.

Reiser et al. (1985) concluded that determining potential needs for flushing flows required consideration of six points:

1. Physical location of the water development in relation to major sediment sources
2. Topography and geology of the area
3. Susceptibility of the drainage to catastrophic events
4. Sensitivity of target fish species and their life history stages to sediment depositional effects
5. Extent of human-induced activities within the drainage
6. Operational characteristics of the project.

Further, Reiser et al. (1985, 1987) noted that after needs for flushing flows are established, the problem becomes one of selecting the best time for implementation. Here, consideration is given to the species of fish present in the system; life histories of these species; the natural, historical runoff periods that the species have adapted to; and the potential flow available for flushing after the project has been completed. Ideally, the best time for implementing flushing flows is when greatest potential benefits to the biological community can be derived. Since no single, standard approach to determine appropriate flushing flows exists, the most reliable method for establishing required flushing-flow rates is to observe the effects of various test flow releases in the stream of interest (Reiser et al. 1985, 1987). Results from research currently underway by Wesche et al. (1983) should help improve our understanding of appropriate methods to determine flushing flow necessary for maintaining stream channels.

Reservoir Effects on Downstream Temperature Patterns

Amplitudes of both daily and seasonal natural temperature regimes also can be significantly altered downstream, depending primarily on the depth of the reservoir outlet. In fact, no daily thermal cycles exist for waters in the initial stream reaches below reservoirs having deep-water outlets. Daily fluctuations, however, do tend to increase with distance downstream below the dams, especially as tributary inflows contribute greater influences to the downstream flows (Ward 1974).

Because natural lakes and reservoirs that have surface water outlets release warmed water relatively soon after heating, temperatures in downstream waters can often be considerably warmer than upstream waters during much of the spring, summer, and early fall (Martin and Arneson 1978, Wright 1967). But in reservoirs having deep-water outlets, heated surface waters accumulate in the upper layers during most of the spring and summer,

while cooler, deeper waters are discharged (Martin and Arneson 1978, Wright 1967). Then, during most of the fall and winter, cool influent waters tend to be stored in the upper layers of the reservoir, while warmer, deeper layers are discharged. Consequently, compared with temperatures in tributary inflows, water downstream of deep-release reservoirs tend to be cooler during the spring and summer and warmer during the fall and winter. This warming of downstream waters during the winter can alter or even prevent downstream ice formation (Neel 1963).

Studies of benthic macroinvertebrates below reservoirs indicate that the greater seasonal consistency of temperature reduces the numbers of resident species by providing competitive advantages to one or a few species; seasonal colder summer waters can slow larval development and prevent maturation and life cycle completion for some invertebrates; and seasonal warmer temperatures can speed the morphogenic development of some invertebrates, causing early (winter) emergence of some species (Ward 1974, 1976). Presumably, similar physiological and developmental relationships also hold for fish downstream of deep-release reservoirs. Certainly, warm summer temperatures can exclude former resident fish species below some reservoirs (Young and Maughan 1980).

Reservoir Effects on Downstream Nutrient Patterns

Another potentially major impact created downstream of reservoirs is the change of natural nutrient input patterns. Construction and filling of reservoirs flood terrestrial environments, leading to leaching of chemicals from flooded soils and from rotting forest debris. Decaying forest materials consume dissolved oxygen and elevate carbon dioxide, nutrients, and dissolved organic materials. As a result, heavy algae growths can be supported, undesirable levels of color and odorous substances may be produced, and conditions that enhance aquatic productivity or that can be toxic to aquatic life may result (Canter 1985, Hendricks and Silvey 1977, Sylvester 1965). Reservoirs, even at high elevations, also can permit the growth of nitrogen-fixing algae (Marcus 1987).

All of these substances become available for discharge from reservoirs, particularly from those with deep-water releases, since these materials tend to concentrate in the deep waters of reservoirs and lakes (Martin and Arneson 1978, Wright 1967). Consequently, productivities downstream of reservoirs can be enhanced over upstream rates, and this may lead to productivity enhancements in downstream fish populations (Marcus 1980, McConnell and Sigler 1959, Neel 1963, Pfitzer 1954). In the most extreme cases, the downstream discharges of chemicals can produce nuisance growths of aquatic weeds and toxic conditions to fish (Baxter 1977, Petts 1984).

Mitigating Downstream Impacts from Reservoirs

Various methods are available to at least partly mitigate the effects of blocked migration routes on stream fishes. R. W. Nelson et al. (1978) discussed various trap and h systems, fishways, conduits and culverts, and turb bypasses potentially useful to permit fish to pass beyo the dam structure. Also, Nettles and Gloss (1987) pres an example of using radio-tagged salmon smolt to eva ate the effectiveness of a bypass structure and vario orientations of trash racks at a small-scale hydroelect site. They found that the bypass structure and angl trash racks significantly reduced entrainment through t penstock and turbine.

Methods are available to minimize the diversity potentially adverse impacts and to manage fisher below reservoirs (Marcus 1987, R. W. Nelson et al. 19 Petts 1984). These include alternative scheduling of wa releases to optimize needed flows, discharging water fro alternative reservoir depths to manipulate water temp atures and water qualities, and physical enhancemen of downstream environments.

Impacts of Mining and Mining Reclamation on Forest Water Quality

Mining-related activities can degrade water qualiti and destroy physical habitats of salmonids. Often as consequence of either metal or coal mining operation dissolved concentrations of heavy metals and acids a increased in the adjoining surface waters. The resulti concentrations can be toxic to fish and other aquat organisms and serve as instream barriers to migratio (Canton and Ward 1977, Duff 1972, Gray and Ward 19 Herricks 1977, Lewis 1977). Metals most frequent associated with mining-related toxicity to aquatic orga isms in the central Rocky Mountains include zinc, co per, cadmium, and lead (Davies and Woodling 198 Roline 1982). These metals can also bioaccumulate organisms and present potential hazards to those co suming the organisms (Parkhurst et al. 1983, Rolin 1982).

In addition to the direct toxic effects from the materials, metals generally precipitate from solution solution pH increases and coat bottom materials wit hydrous metal oxides. Frequently, this occurs dow stream from a mining-contaminated stream after i confluence with an uncontaminated stream. These dep sitions can decrease abundances of periphyton and be thic macroinvertebrates and decrease potentials fo spawning success downstream from the confluenc (McKnight and Feder 1984, Roline 1982).

Instream sediment loads also tend to increase as a co sequence of mining-related physical disturbance including haul road activities, runoff from mine tailin piles, and washout of settling ponds (American Fishe ies Society 1982). Additional sediment problems and th total, if only temporary, destruction of instream and ripa ian habitat also can result from mining of stream and lak bottoms (Harvey 1986, McLeay et al. 1987, Thomas 1985

Acid- and metal-containing waters from mine sites ca be treated through a variety of proven technologies t remove toxic potentials, allowing recolonization by fis and other aquatic organisms (e.g., Herricks and Cairn

977, Reiser et al. 1982, Todd et al. 1982). Also, several iable methods are available for restoring mined streams Gore 1985). The AFS Western Division Riparian Habitat Committee (American Fisheries Society 1982) has resented a selection of best management practices that re useful not only to protect and manage riparian communities along western streams associated with mining, ut also to minimize associated instream impacts. These nclude adherence to NEPA (National Environmental Proection Act) regulations, thoughtful development of mine peration plans, creation of streamside buffer zones, contruction of settling ponds, appropriate channelization nd culvert installation procedures, definition of nstream flows needs, providing for overburden segregaion, control and treatment of mine wastewaters, correct nine site revegetation practices, and minimizing impacts rom suction dredging.

Impact of Recreation, Fishing, and Fish Stocking

mpacts of Recreation

Generally, nonconsumptive recreation has not been irectly linked with reductions in salmonid populations, ut it has been coupled with water quality changes. Often, campgrounds or water-based recreation do not sigificantly lower water quality (Aukerman and Springer 976, Gary 1982, Gary and Adams 1985). Nonetheless, Aukerman and Springer (1976) suggested that campgrounds accessible to automobiles did increase bacterial vater pollution more than did backpack campgrounds. And Johnson and Carothers (1982) reported that recreaionists may concentrate use in riparian zones and thus ncrease soil compaction and vegetation damage. Potter t al. (1984) noted that ski areas may contribute signifiant amounts of sediment to streams, and could desynhronize snowmelt and lead to unusually high peak lows. Snow making at ski areas also can reduce streamlows. Due to poor sewage disposal, homes located in orested watersheds may elevate concentrations of coliorm bacteria and nutrients in streams (Ponce and Gary 979, Potter et al. 1984).

ffects of Fishing and Fishing Regulations

Under some circumstances, anglers possess the abilty to alter the size, structure, and distribution of fish opulations. Bjornn et al. (1977b) stated that cutthroat rout in certain northern Idaho streams could be fished o extinction, if it was permitted. Alternatively, regulaions restricting bait fishing and the harvest of fish under 0.5 cm did not increase the abundance of brown and ainbow trout in a northern Colorado stream (Klein 1974). Yet Wesche et al. (1987b) found stream accessibility to nglers was significantly related to the standing stocks f brown trout in southeastern Wyoming streams. Therefore, trout must be susceptible and accessible to anglers f regulations are to affect trout populations.

Restrictive regulations have produced dramatic changes in trout populations. The mean length of Yellowstone cutthroat trout in Yellowstone Lake has increased approximately 20 mm since the implementation of a two-fish, 330-mm maximum-size limit (Gresswell 1982). After 5 years of a three-fish, 330-mm minimum-size limit, cutthroat trout abundance increased fourfold in the St. Joe River in Idaho (Johnson and Bjornn 1978). Over the same interval, but under no-kill restrictions, the cutthroat trout population in Kelly Creek expanded nearly 1,200% (Bjornn et al. 1977b). Anderson and Nehring (1984) noted that a no-kill section of the South Platte River contained a larger biomass of trout and a larger proportion of trout greater than 30 cm long than did a section with an eight-fish-per-day limit. Thus fish populations can respond to restrictive regulations in some circumstances.

Not all trout species are equally susceptible to angling. In a small Idaho stream after 32 hours of fishing, anglers removed 31% of the cutthroat trout but only 7% of the brook trout (MacPhee 1966). Furthermore, fish greater than 15 cm were more vulnerable than smaller trout. Nyman (1970) noted that brown trout were less likely to be caught by anglers than were brook trout. Similarly, anglers more readily caught rainbow trout than brown trout, but both brown and rainbow trout greater than 30 cm were more susceptible to angling than were smaller fish (Anderson and Nehring 1984). Data from Favro et al. (1986) indicated that anglers more frequently captured both brown and rainbow trout greater than 33 cm than did electrofishing. Young (1986) noted that westslope cutthroat trout greater than 30 cm in length were more than twice as vulnerable to angling than were smaller trout in a western Montana river. Based on the available data, vulnerability to angling appears to be greatest for cutthroat trout, then brook trout, then rainbow trout, with brown trout seeming to be the least vulnerable. Also, susceptibility to capture by anglers apparently increases with trout size.

Impacts of Fish Stocking

Stocking consists of introducing nonnative or hatchery-produced fish to streams and lakes. Stocking has created a number of salmonid fisheries in streams historically lacking trout, e.g., the North Platte River drainage in Colorado and Wyoming (W.A. Hubert, Wyoming Cooperative Fish and Wildlife Research Unit, Laramie, personal communication). Additionally, the recovery of the federally threatened greenback cutthroat trout has relied heavily on the introduction of hatchery-reared fish (U.S. FWS 1983). Nonetheless, the potential for interaction between hatchery-raised and wild fishes should be evaluated prior to stocking (Li and Moyle 1981).

Trout stocking may have a significant impact on naturally reproducing trout populations. Vincent (1987) reported that 4 years after the cessation of stocking catchable-size rainbow trout in the Madison River in Montana, the fall populations of wild brown and rainbow trout had increased by 160% and 870%, respectively, despite an estimated 40% increase in angling pressure

over those 4 years. He speculated that stocking produced increased stress via disruption of stable dominance hierarchies and thus led to greater mortality in wild fish. Bohlin (1977) noted that "resident" brown trout tended to repel "introduced" fish, but perhaps this behavior could be overridden if densities of introduced fish were high. Pollard and Bjornn (1973) noted that introduced rainbow trout took over feeding sites previously occupied by juvenile steelhead.

Introductions of nonnative salmonids can also lead to hybridization. Hybridization with rainbow trout may pose the greatest threat to the preservation of various subspecies of cutthroat trout (Leary et al. 1984). And hybrids between native bull trout and introduced brook trout have been found in one Montana stream (Leary et al. 1983). Furthermore, the genetic content of hatchery trout and wild trout of the same species often differ radically; Allendorf and Phelps (1980) found a 57% reduction in polymorphic loci, a 29% reduction in the average number of alleles per locus, and a 21% reduction in the average heterozygosity in hatchery stocks of westslope cutthroat trout compared with wild stocks. Ryman and Stahl (1980) noted similar changes in hatchery populations of brown trout.

Hybrids between different species (and between different stocks of a single species) tend to possess greater developmental instability due to the loss of coadapted gene complexes, and this has been associated with reduced fitness in several interspecific hybrids of salmonids (Leary et al. 1985). Thus, if hatchery fish breed with wild fish, their offspring may suffer greater mortality. Fraser (1981) reported that survival of wild brook trout was greater than that of a hybrid of two wild stocks. In comparisons of wild, hatchery, and wild-hatchery crosses of steelhead trout, wild fish had significantly greater survival in streams than did hatchery fish or wild-hatchery fish (Reisenbichler and McIntyre 1977). Interestingly, hatchery fish survived significantly better in a hatchery pond than did the other two groups.

Urbanization Impacts on Water Quality, Aquatic Habitats, and Fisheries

A variety of studies have shown that urbanization can affect streams through physical changes, including removal of riparian vegetation and channelization, and chemical changes, including point and nonpoint pollution sources. Overall, urbanization tends to accentuate peaking flows of stormwater runoff; elevate suspended and bed loads for sediment; plus increase dissolved concentrations of petroleum products, heavy metals, other toxicants, and nutrients, particularly phosphorus and nitrogen (cf., Davies 1986, Dillon and Kirchner 1974, Schillinger and Stuart 1978, Shapiro and Pfannkuch 1973).

A series of studies comparing the physical, chemical, and biotic conditions of Kelsey Creek in Bellevue, Washington, with conditions in a nearby nonurban reference stream provides perhaps the most complete analysis of the influences by urbanization on the trophic structure and salmonid fishery in a stream (Pedersen a[nd] Perkins 1986, Scott et al. 1986, Sloane-Richey et al. 198[1]). Urbanization changed the stream's hydrologic regime a[nd] its channel morphology, which caused increased run[off], scouring of attached algae and allochthonous materia[l], increased suspended sediment, decreased streambed s[ta]bility, and increased light and nutrient availabil[ity] (Sloane-Richey et al. 1981). Removal of riparian vege[ta]tion reduced inputs of allochthonous debris. Also, t[he] deposits of fine silts had relatively lower carbohydr[a]t[e] contents. Thus, not only was the temporal availability [of] particulate organic material limited in the system, but [its] value as food was also limited. Its quality was, howev[er,] sufficient to support invertebrate growth (Richey 198[ ]).

Comparing invertebrate populations colonizing arti[fi]cial substrates in these streams suggested there was [no] significant difference in their population densities, b[ut] the biomasses sometimes were 4 times greater in t[he] urban stream (Pedersen and Perkins 1986, Richey 198[ ]). The dominant taxa in the urbanized stream were bu[r]rowers tolerant of unstable substrates. Kelsey Creek al[so] lacked benthic taxa adapted to utilize large particula[te] organic material, while such taxa were abundant in t[he] reference stream. [This is consistent with the observa]tion by Sloane-Richey et al. (1981) that large organ[ic] debris was largely absent from Kelsey Creek.] Amph[i]pods, one of the most common invertebrates in Kels[ey] Creek, often were flushed from the creek during run[off] events.

The abundance of invertebrates in Kelsey Creek wa[s] adequate, however, to support populations of co[ho] salmon and cutthroat trout; total biomass of fish was n[ot] markedly different between these streams (Scott et [al.] 1986). Growth rates for salmonids in the urban strea[m,] in fact, exceeded those in the reference stream, and [ ] cutthroat reached the smolt stage and migrated dow[n]stream 1–2 years earlier than occurred in other le[ss] productive streams in the region. This increase in grow[th] rate for salmonids in the urban stream appeared to [be] related to warmer stream temperatures caused by remo[val] of riparian vegetation, and the sometimes greater abs[o]lute densities of benthic invertebrates in the urban strea[m].

Neither increased storm runoff peaks nor increas[ed] pollutant load pulses appeared to increase early dow[n]stream migration or displacement of salmonids from t[he] urbanized stream, though some evidence suggested th[at] other fish taxa may have been affected by such even[ts]. Streambed scouring and instability did appear to mar[k]edly reduce spawning habitats available for coho a[nd] sculpin, causing egg mortality in these species. M[ost] salmon in Kelsey Creek appear to hatch in a tributa[ry] stream that drains a relatively undeveloped section of t[he] watershed. Cutthroat trout appeared to be much mo[re] successful in finding satisfactory spawning habitat in K[el]sey Creek.

In total, fish diversity in urbanized Kelsey Creek w[as] less than in the reference stream: proportions a[nd] biomasses of cutthroat trout were greater, while those [for] coho salmon, longnose dace (*Rhinichthys cataracta[e]*), largescale suckers (*Catostomus macrocheilus*), and scu[l]pin (*Cottus* spp.) were less. Age-0 cutthroat were fou[nd]

o predominate in Kelsey Creek and other urbanized treams in the drainages of the Puget Sound. Overall for ributaries to Lake Washington, proportions of cutthroat rout directly correlated with proportions of impervious rea (e.g., asphalt or concrete) within the watersheds, vhile the fish diversity inversely correlated with impervious areas (Scott et al. 1986). Thus, cutthroat trout ppear to be somewhat less sensitive to disturbance relaive to other salmonid and nonsalmonid taxa in these treams.

Cumulative Impacts

Impacts to aquatic systems and fisheries rarely occur n isolation, but rather often originate from multiple ources, produce multiple effects, and extend to subseuent downstream reaches. Regulations promulgated by he Council of Environmental Quality under the National nvironmental Policy Act of 1970 require that environmental impact statements contain evaluations of cumuative effects, which are defined (40 C.F.R. 1508.7) as

> . . . the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

Coats (1987) and Coats and Miller (1981) present an 18-ompartment conceptual model showing how timber arvest can relate to hydrological and erosional processes nvolved in cumulative watershed effects. Salo and Cederholm (1980) suggest five processes that can act in cumulative manner on aquatic organisms in streams:

1. Increases in suspended or deposited sediment
2. Changes in diurnal or seasonal temperatures producing patterns outside the natural extremes
3. Changes in the physical habitat produced by excessive increases or decreases in loads of organic materials
4. Detrimental changes in other water quality parameters
5. Detrimental changes in water quantity and flow regimes.

To deal with the general lack of specific data on effects, umulative watershed effects (CWE) evaluations are often ompleted through development of models using quivalency tables based on different forest management ctivities and effects threshold indices (e.g., Klock 1985). hen, through these tables, various management activiies can be evaluated and rescheduled, if necessary, to "prevent" cumulative effects from occurring. Such escheduling may include postponing certain percentges of scheduled timber harvests. However, there has een little evaluation on whether such CWE modeling pproaches are achieving their goals (Ice 1987).

Many such CWE models incorporate considerable potential error (Grant 1987, Harr 1987). First, there is substantial doubt that actual effects thresholds exist. Second, all models that attempt to minimize impacts by rescheduling include the assumption that the principal downstream effects are caused by peak flow increases; however, recent results indicate that increased sediment delivery and transport of large woody debris are more important than peak flows (Grant 1986, 1987). Third, such models make no allowance for basin differences in hydrologic responses to forest practices and geomorphic responses to hydrological changes. Finally, current approaches to mitigate impacts do not include monitoring to determine whether the methods are working. Overall, many such models include the erroneous belief that "*simplicity can be willed on the forest hydrological system*. This belief encourages the implementation of simplistic guidelines, the adoption of arbitrary thresholds of concern, and the search for all-encompassing methodologies to predict consequences of forest activities on water resources" (Harr 1987:137).

Grant (1987) emphasizes that cumulative effects must be analyzed individually. Each case will involve a wide range of hydrologic and erosional phenomena, complexly linked by a cascading series of causes and effects (Grant et al. 1984). For example, Grant (1987) suggests that potential effects related to peak flows, one of several classes of potential cumulative watersheds effects, can be decomposed and addressed through a series of five questions:

1. How do harvest activities affect peak flows?
2. How are increased peak flows routed to and through the stream network?
3. How do increased peak flows in channels affect frequency of movement of bed and bank materials?
4. How do changes in frequency or timing of movement of bank and bed materials affect channel structure and stability?
5. How do changes in channel structure or stability affect aquatic communities?

To address such questions requires integrating existing knowledge, future research results, and specific data from the field.

APPROACHES FOR MANAGING AND EVALUATING SALMONID HABITAT

Methods for Monitoring and Evaluating Salmonid Habitat Quality

Once the variables that constitute salmonid habitat have been defined, the next step is to evaluate the quality of the habitat based on some measure of the variables. Following this, the variables can be monitored through time to detect changes in habitat quality. Unfortunately, researchers have failed to consistently define, evaluate, and sample the aforementioned variables, making comparisons of different studies difficult (Armantrout 1982). Various researchers have attempted to develop a field-validated, statistically sound, unified system of habitat assessment (Platts et al. 1983b; USDA Forest

Service 1988). Note, however, that the definition of habitat quality is difficult and equivocal, and that a single definition of quality does not apply to all salmonid species or their habitats (Binns and Eiserman 1979, Bowlby and Roff 1986, Kozel 1987). Consequently, we chose to list a portion of the currently available techniques (table 3).

Techniques for Restoration, Rehabilitation, and Enhancement

A frequently employed approach to manipulating the physical habitat in streams is by altering the actual appearance of the stream channel by placing artificial structures within the stream. In use, these structures can improve fisheries habitat by reducing bank erosion, increasing habitat diversity through creating new series of riffles and pools, providing cover, or improving substrates suitable for spawning. For example, installing small rock dams and

Table 3.—Some techniques for directly or indirectly assessing salmonid habitats.

Sample design and analysis	Green 1979 Seber 1982 Armour et al. 1983 Platts et al. 1983b Snedecor and Cochran 1980
Stream habitat surveys	Armour and Platts 1983 Cuplin 1974 Duff and Cooper 1976 Greentree and Aldrich 1976 Heller and Baker 1974 Oswood and Barber 1982 Pfankuch 1975 Platts et al. 1983b Platts et al. 1987 Rinne 1985 Seehorn 1970 USDA Forest Service 1970 USDA Forest Service 1988
Impact assessment	Green and Vascotto 1978 Hall et al. 1978 Hurlburt 1984 Stewart-Oaten et al. 1986
Fish population estimates	Hankin 1984 Hankin 1986 Hankin and Reeves 1988 Platts et al. 1983b Rinne 1985 Slaney and Martin 1987 Van Deventer and Platts 1983
Invertebrate assessment	Jackson and Resh 1988 Winget 1985
Habitat variable definition	Binns and Eiserman 1979 Bisson et al. 1982 Bovee and Cochnauer 1977 Bowlby and Roff 1986 Everest et al. 1982 Milhous et al. 1981 Platts et al. 1983b Platts et al. 1987 Rosgen 1985 Wesche 1980

deflectors in a small mountain stream in Quebec not only increased the biomass of brook trout, but also increased biomasses of aquatic invertebrates and increased usage of the stream by mink and raccoons (Burgess 1985).

Wesche (1985) presented a comprehensive discussion on the relationship of fish with components of their habitat, including stream velocity, substrate, depth, invertebrate drift, spawning areas, and protective cover. In reviewing the use of artificial structures, he concluded that the most commonly used within-channel structures are current deflectors, low profile overpour dams and weirs, bank cover, and boulder placement. Table 4 lists the commonly used options available for enhancing stream habitats. Both Wesche (1985) and R.W. Nelson et al. (1978) provide guidance on appropriate application, construction, and installation techniques for the structures. However, Reeves and Roelofs (1982) noted that the changes in fish populations caused by such enhancements are rarely evaluated. Thus funds for evaluation of structures should be considered a part of habitat improvement projects.

Developing and Using Models to Estimate Potentials for Stream Fisheries

Maximum habitat available for stream fisheries depends ultimately on the volume of water flowing down the stream during the specified period. Consequently, much research has focused on relationships among stream fisheries, habitats, and flows. This research has been extensively reviewed by Wesche and Rechard (1980), Loar and Sale (1981), Terrell (1984), Armour et al. (1984), EA Engineering, Science and Technology, Inc. (EA ES&T 1986), and Fausch et al. (1988). Included in the review by EA ES&T (1986) were 54 instream flow and habitat quality methods, while 99 models were reviewed by Fausch et al. (1988). Rather than again reviewing the available models, this section focuses on considerations important when developing, evaluating, and using these models.

Most instream flow and habitat investigations endeavor to develop techniques and models through which standing crops and/or other measures of biological productivity, generally pertaining to fish, can be described or predicted using a set of habitat variables. Underlying all of the resulting models is the premise that for flow, as well as for other environmental measures, there are definable limits, beyond which conditions become unsuitable for fisheries. Somewhere between these upper and lower extremes, optimal conditions exist that grade predictably to the unacceptable conditions. Ultimately, after the appropriate relationships are derived, it is hoped that a few well-chosen, easily obtained measurements made for a stream can be entered into a model to predict the stream's potential carrying capacity and/or standing stock of fish.

Present models, which have been developed using both qualitative and quantitative approaches, include as few as 1 to as many as 21 input variables (EA ES&T 1986). Some models use variables that are transformed from

able 4.—Trout habitat enhancement structures and practices with references describing their application. Information on unreferenced items can be found in R. W. Nelson et al. (1978) and Wesche (1985).

urrent deflectors
- Rock-boulder deflectors
- Gabion deflectors—House and Boehne 1986
- Double-wing deflectors—Seehorn 1985
- Underpass deflectors
- Half log deflectors—Stuber 1984
- Boulder placement—House and Boehne 1985
- Trash catchers

ow-profile check dams
- Rock-boulder dams—Reeves and Roelofs 1982
- Single and multiple log dams—Rinne 1981
- Plank or board dams
- Gabion check dams—Binns 1982b
- Beaver introduction

ank cover treatments
- Log overhangs
- Artificial overhangs—Brusven et al. 1986
- Tree revetments—Binns 1986
- Bank revegetation—McCluskey et al. 1983
- Riprap—Knudsen and Dilley 1987
- Erosion-control matting
- Streambank fencing
- Grazing control
- Buffer strips—Barton et al. 1985
- Adding large organic debris—Boehne and Wolfe 1986

ediment removal
- Settling basins—Hansen 1973
- Scour and storage—Klassen and Northcote 1986
- Riffle sitter—Hall and Baker 1982

erived (recombined) using previously measured varia-les. Overall, the variables include details on basin iorphology, channel morphology, flow rates, habitat ructure, species present, and other physical and chem-cal measures.

Assorted real and potential problems are associated ith all existing habitat models (EA ES&T 1986, Fausch al. 1988). Probably most damaging in the long term the lack of standard methods for use in measuring abitat variables (Armantrout 1982, Fausch et al. 1988, carnecchia and Bergersen 1987, Wesche 1983). Because iethods used to collect data are reflected in any result-ig models developed, single data sets cannot be ccurately explored using otherwise similar models that ere developed using alternative sampling methods.

Various problems associated with many of these iodels have statistical bases (Fausch et al. 1988). First, resentations for most models lack information neces-iry to critically evaluate how the model was statistically r otherwise) selected or how the model may perform general applications.

Second, many of these models are based on small sam-le sizes. This can limit the potential applicability of the iodel to only conditions within the restricted range of ie data used in its development. If models are used to ktrapolate outside these limits, the resulting predictions an be biased and unreliable. This restriction must be rongly considered when applying models to habitat con-itions other than those used to develop the model. Emphasis of this detail is often neglected by model developers when promoting general application of their own models, and ignored by investigators when applying and criticizing models developed by other investigators (see Scarnecchia and Bergersen [1987] for an exception).

Third, rarely have errors associated with measuring habitat variables been evaluated during model development (Fausch et al. 1988). If measurements upon which models are based are biased, the model will yield similarly biased predictions. Most models have not been tested with data that was not used in developing the models; thus we know little of their overall realism, precision, or generality (Levins 1966).

Fourth, use of derived variables, including indices, ratios, proportions, and percentages, creates a potential tangle of statistical problems (Green 1979, Sokal and Rohlf 1981). These can include (1) greatly increasing the variance of the derived variable relative to the original variables; (2) potentially yielding biased estimates of the true means for derived variables; (3) subsequently, potentially producing unusable, nonnormal, and possibly intractable distributions for derived variables; and (4) a frequent tendency to obscure rather that clarify intervariable relationships. Despite these problems, we sometimes have no choice other than to use derived variables.

Various potentially unreasonable assumptions about habitat relationships are also implicit in many of these models (Annear and Conder 1984, EA ES&T 1986, Fausch et al. 1988, Mathur et al. 1985). These include the assumptions (1) that fish primarily respond to average water velocities at some defined depth below the surface (e.g., 0.6X); (2) that stream depths, velocities, and substrates are not related to each other (i.e., an important underlying assumption in regression analysis, through which most habitat models are developed, is that the independent variables are uncorrelated); and (3) that large amounts of suboptimal habitat are equivalent to small amounts of optimal habitat. Yet, studies show that fish respond more to flow differences in the microhabitats; that many habitat variables, including stream depths, velocities, and substrates, are often highly correlated; and that suboptimal habitats can often be uninhabitable (Fausch 1984, Fausch et al. 1988, Grossman and Freeman 1987, Moyle and Baltz 1985, Shirvell and Dungey 1983).

Finally, most models often include the assumption that measured densities or biomasses of fish in streams are at carrying capacities for the habitat and that these carrying capacities are defined by the physical and chemical conditions measured in the habitat. This assumption precludes such effects as predation (including fishing), competition, or some other unmeasured environmental variable as having any potential influences on the populations (Conder and Annear 1987). For example, both Grossman et al. (1982) and R. L. Nelson et al. (1987) suggest that unpredicted environmental disturbances can be the most important regulator of fish community structure.

Of the available models, the Habitat Quality Index (HQI), developed by Binns (1979, 1982a) and Binns and Eiserman (1979) in Wyoming, often provides reasonable

predictions of standing crops for trout in unregulated, coldwater streams in the central Rocky Mountains (Annear and Conder 1983, 1984; Conder and Annear 1986; EA ES&T 1986). But this model, too, has the problem of including many nonindependent variables (i.e., multicollinearity). And, it includes many subjective variables that can be difficult to score (see Scarnecchia and Bergersen 1987).

Other models have recently been developed relating salmonid population to habitat variables in the central Rocky Mountains (e.g., Chisholm and Hubert 1986, Lanka et al. 1987, Scarnecchia and Bergersen 1987, Wesche et al. 1987b, Winkle 1988). These models all show good applicability to the specific range of habitat conditions that they address. Yet, these models still are limited by the range of habitat data included in model development, inclusion of nonindependent variables without an evaluation of the potential problem caused by the inherent multicollinearity, and inclusion of sometime subjective and/or derived variables. The potential severity of these problems in these and other such models awaits evaluation. As the quest for the "best" salmonid-habitat model continues, we will likely find in the end that the ultimate solution will be a series of highly specific models developed to address specific habitat related problems for specific types of habitats.

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This report includes a general review and analysis of the literature summarizing the available information relevant to salmonid-habitat relationships, particularly as it pertains to the central Rocky Mountains. Also included is a comprehensive indexed bibliography.

Keywords: See Index to Bibliography

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Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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Flagstaff, Arizona
Fort Collins, Colorado*
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Lincoln, Nebraska
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Tempe, Arizona

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526

United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-189**

An Analysis of the Outdoor Recreation and Wilderness Situation in the United States: 1989–2040

A Technical Document Supporting the 1989 USDA Forest Service RPA Assessment

H. Ken Cordell, John C. Bergstrom, Lawrence A. Hartmann,
and Donald B.K. English

Preface

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), P.L. 93-378, 88 Stat. 475, as amended, directed the Secretary of Agriculture to prepare a Renewable Resources Assessment by December 31, 1975, with an update in 1979 and each 10th year thereafter. This Assessment is to include "an analysis of present and anticipated uses, demand for, and supply of the renewable resources of forest, range, and other associated lands with consideration of the international resource situation, and an emphasis of pertinent supply, demand and price relationship trends" (Sec. 3.(a)).

The 1989 RPA Assessment is the third prepared in response to the RPA legislation. It is composed of 12 documents, including this one. The summary Assessment document presents an overview of analyses of the present situation and the outlook for the land base, outdoor recreation and wilderness, wildlife and fish, forest-range grazing, minerals, timber, and water. Complete analyses for each of these resources are contained in seven supporting technical documents. There are also technical documents presenting information on interactions among the various resources, the basic assumptions for the Assessment, a description of Forest Service programs, and the evolving use and management of the Nation's forests, grasslands, croplands, and related resources.

The Forest Service has been carrying out resource analyses in the United States for over a century. Congressional interest was first expressed in the Appropriations Act of August 15, 1876, which provided $2,000 for the employment of an expert to study and report on forest conditions. Between that time and 1974, Forest Service analysts prepared a number of assessments of the timber resource situation intermittently in response to emerging issues and perceived needs for better resource information. The 1974 RPA legislation established a periodic reporting requirement and broadened the resource coverage from timber to all renewable resources from forest and rangelands.

USDA Forest Service
General Technical Report RM-189

April 1990

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A Technical Document Supporting the 1989 RPA Assessment

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Contributors to chapter I, The Outdoor Recreation and Wilderness Resource Base, were Walter Cook (University of Georgia)—nonfederal wilderness areas; Douglas McEwen (Southern Illinois University)—private campgrounds; Linda Profaizer (Woodall's Publishing Company)—commercial facilities; Laura Szwak (National Park Service)—nonprofit organizations; Brett Wright (George Mason University) and Allen Rowell (formerly Forest Service)—nonindustrial private forest lands; Pat Reed—wilderness; Jim Absher (University of Georgia)—wilderness substitutes; Ellen Absher (Consultant)—state recreation lands; Barbara McDonald (National Oceanic and Atmospheric Administration)—local government recreation; and Gail Vander Stoep (University of Massachusetts)—interpretation resources.

Contributors to chapter II, The Demand for Outdoor Recreation and Wilderness, included Joe O'Leary (Purdue University)—demand modeling and social trends; Gina McLellan (Clemson University)—trends in outdoor recreation; Helen Freilich (Forest Service)—trends in population participation; Kathy Andereck, Muzzafer Uysal (Clemson University), and Marsha Iyomasa (formerly U.S. Travel and Tourism Administration)—international tourism; Pam Walker (Forest Service)—recreation and the disabled; Alan Ewert (Forest Service)—high risk recreation; Carter Betz (formerly Forest Service)—federal/state comparisons; Pat Reed—nonrecreational use of wilderness; Barbara McDonald—local area participation; Betsy Sale (Virginia Commonwealth University)—user attitudes, expectations and conflicts; Carter Betz—projections; and Dan Hope (University of Georgia)—demand trends.

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Contents

Many different people and organizations assisted with data collection. Boy Scouts from Athens, Georgia, helped with the survey of private landowners.

HIGHLIGHTS: OUTDOOR RECREATION AND WILDERNESS IN AMERICAN LIFE

Outdoor recreation and wilderness are part of our merican heritage. The President's Commission on mericans Outdoors (1986) observed:

> The majesty of the great outdoors helped make America and Americans what we are today. No mere coincidence matched a national character of independence, of resourcefulness, and of generosity, with a land of splendor, vastness, and inspiration.

ot only is the out-of-doors a central part of our history, is also an important part of our contemporary lives.

People go outdoors for many reasons—for exercise, hallenge, competition, relaxation, a change of pace or cenery, for beauty, to be with family or friends, solitude and contemplation, or to study nature or history. opular activities include driving, walking, swimming, amping, picnicking, skiing, or playing sports such as aseball or soccer. But Americans also birdwatch, study istory, garden, rockclimb, windsurf, and sunbathe. In ct, a single outing typically involves several activities. riving, picnicking, socializing with family or friends, nd observing nature could easily be included in a sinle trip.

People enjoy the outdoors from their own urban backards to remote wilderness. Their enjoyment often beins well before they arrive and often lasts long after they eturn. Other people enjoy and value these areas, especially wilderness, without ever traveling to them.

The outdoors offers only one of the many alternative ays that people can occupy their leisure time. Video novies, computer games, a variety of indoor sports, plays and social events, and restaurant dining attract people indoors. While the ways people spend their leisure is changing, people experience a continuing need to go outdoors as a contrast to the indoor lives they lead. The Domestic Policy Council's Task Force on Outdoor Recreation Resources and Opportunities (1988) eloquently summarized this situation:

> Whatever it may be, outdoor recreation is a leisure moment outdoors, freely enjoyed. It has no boundaries and no bounds beyond those of wondering and wandering in the outdoor environments—not even the spacious skies, the majestic purple mountains, the sunrise or sunset, and the ever-changing seasons which bring a new dimension to each moment and each day. Outdoor recreation is life rejoicing in the outdoors.

The Values of Outdoor Recreation and Wilderness

Americans benefit from outdoor recreation and wilderness in many ways. The President's Commission put it this way: "Outdoor recreation helps us accomplish personal goals—fitness and longer life, family togetherness, friendship, personal reflection, and appreciation of nature and beauty" (PCAO 1986). The Commission identified a number of social, economic, and environmental benefits stemming from outdoor recreation.

Outdoor recreation contributes to personal health. Physical fitness is a primary reason for engaging in outdoor sports, but outdoor activities also contribute to mental health by reducing stress.

Outdoor recreation creates jobs and invigorates local economies. In addition to consumer spending for outdoor recreation ($132 billion in 1986) (Domestic Policy Council 1988), local and regional economies benefit from the jobs, taxes, and tourism generated both directly and indirectly by the demand for outdoor recreation.

Outdoor recreation contributes to family cohesion. In one study, families said they pursued outdoor activities to strengthen family ties. It provides links between generations such as when parents teach their children to hike, camp, identify wildlife, hunt, or fish.

Outdoor recreation can help prevent crime. Young offenders in a program that featured outdoor sports and other outdoor activities had a far lower rate of repeat offenses than did participants in five other nonoutdoor programs.

The outdoor environment enriches America's culture as evidenced by books, plays, poetry, and art featuring nature and outdoor activities.

Outdoor activity has stimulated public interest in the quality of the environment and helped generate public support for control of air and water pollution and the preservation of land, water, and wildlife.

Wilderness also produces most of these recreational benefits. In addition, wilderness often provides other nonrecreational benefits to our culture. It helps preserve life-sustaining diversity in nature and some of the best places to measure change in our environment. Air and water are cleansed, and many commercially important fish and wildlife species begin their lives in wilderness.

A Brief History of Outdoor Recreation and Wilderness in America

The natural environment has always been a central element of American culture, yet it was not until the late 1800's that national attention was focused on this natural heritage as a recreation resource. In recent years, the management of forest and rangeland resources for recreation and wilderness uses has become increasingly important.

Outdoor Recreation in America: The Early Years

Native Americans directly depended on the natural environment for all aspects of their lives (Spears and Swanson 1978). Lewis and Clark observed that the men of the mountain tribes were "fond of shooting their arrows at a target made of bark, riding and exercising themselves on horseback, racing, etc." (DeVoto 1953). Early colonists also engaged in outdoor pursuits, often out of necessity, but also for enjoyment. Although Puritan laws or convention discouraged frivolous pursuits, men engaged in activities derived from their work: hunting, fishing, marksmanship contests, and horse racing. During the middle 1800's, the leaders of the "Muscular Christianity" movement agreed that physical fitness was compatible with religious teachings. As a result, activities such as walking, rowing, and ice skating rose in popularity. Women gradually began to participate with men in a greater range of outdoor social events. As outdoor activity increased, attention turned to providing open space where people could exercise, meet other people, or just relax in pleasant surroundings.

The Emergence of Government's Role in Outdoor Recreation and Wilderness

Today, open space is considered the primary outdoor recreation resource. By contrast, the first European settlers were challenged with establishing islands of civilization in a forested "wilderness" which they saw as their Christian duty to subdue with axe and plow. Many colonial communities established public common lands, but their original purpose was grazing of livestock rather than public recreation. However, the founders of some of the nation's first cities, such as William Penn in Philadelphia and James Oglethorpe in Savannah, provided for city squares or other open areas to create more attractive and impressive urban environments. The Spanish settlements in the Southwest usually had plazas which provided space for casual strolling and public meetings (Chubb and Chubb 1981).

Over time, American attitudes toward nature changed. Romanticism, the view that wild nature and a primitive lifestyle had value in and of themselves, grew with the writings of philosophers, poets, and writers such as Rousseau, Byron, and Cooper. Influenced by the romanticist view of nature and the close-to-the-land lifestyles of Native Americans, George Catlin proposed the idea of a "nation's park" in 1833. Coincidentally, it was in that year that the first national preserve—Hot Springs in Arkansas—was established by Congress to protect the springs widely renowned for their therapeutic properties. Later, transcendentalists, such as Ralph Waldo Emerson and Henry David Thoreau, believing that the divine is evident in nature, argued that the value of "wilderness" is the preservation of civilization.

To provide relief from what they feared would become a stifling urban environment, Frederick Law Olmstead and Calvert Vaux designed New York City's Central Park in the 1850's. Their ambition was to maintain open space and provide a place for exercise and relaxation. Central Park was to become a model for open space protection emulated by many cities across the country. Between 1860 and 1890, more than 80 cities established public park systems while playgrounds were developed in connection with schools. Several state and county park systems were established during this period (Chubb and Chubb 1981).

In the late 1800's, attention turned to the vast federal estate of the West. This land was acquired by the United States through purchase (from France and Russia), conquest (from the Native American nations and Spain), and negotiation (from Great Britain). For years, the federal government gave its land to homesteaders and railroads to stimulate development of the West. Later, interest turned to holding portions of the federal lands for the broader public benefit including recreation. In 1864 California persuaded the federal government to turn over

semite Valley to the state for "public use, resort, and creation."

But, a sentiment was growing for retaining in federal nership areas of spectacular scenery. In 1872, Congress tablished the 1.6 million-acre reserve that later became llowstone National Park "as a park or pleasuring ound for the benefit and enjoyment of the people." ong with the establishment of national parks, such as ount Rainier, the Grand Canyon, and other great stern parks, attention turned to the forests. The first rest reserves were established in the 1890's through esidential proclamation.

Unlike the parks, where preservation and recreation re emphasized, the forest reserves (later to become the tional forests) were to ensure a supply of timber for the tion and protect water supplies. But, they also were ailable for recreation. In 1903, President Theodore osevelt designated Pelican Island, Florida, a national ldlife refuge, thus inaugurating a new federal system ecifically aimed at preserving wildlife and their bitats. Federal lands in the West, which had not been ven to private interests, states, or municipalities or in- rporated into other federal land systems, remained as iblic domain, managed by what is now the Bureau of nd Management, and were available for recreation.

By comparison, the East had little federal land on hich to establish national parks and forests. With pas- ge of the Weeks Law in 1911, the federal government gan buying land for national forests in the Appala- ians. Meanwhile, states and philanthropists acquired nd for parks, such as the Great Smoky Mountains and henandoah, and turned them over to the federal overnment.

utdoor Recreation Before World War II

The industrial revolution brought many changes. eam railroads and steamboats opened areas previously cessible only to the most rugged mountain men. owever, the 14- to 18-hour workday and 6-day workweek the industrial revolution left most people little time r recreation. Gradually, working hours declined. By 00, the average worker spent 10 hours a day on the job, d outdoor recreation activity increased fairly dramat- ally.

The mass-produced automobile made the outdoors ac- ssible to millions of Americans following World War Visitation to national parks and other recreation areas rew rapidly through the 1920's. Although the Great epression of the 1930's had a devastating effect on the ation's economy, job-creation programs, especially the ivilian Conservation Corps, benefited thousands of city, ate, and federal recreation areas through rehabilitation nd development of high-quality facilities.

utdoor Recreation After World War II

As millions of servicemen and women returned to ivilian life after World War II, demand for outdoor creation and an economy to support it grew. Many new families were started during the "baby boom," and the population grew rapidly. The quality of automobiles and roads increased, fuel became cheaper, and the average workweek declined to 40 hours over 5 days. Outdoor recreation opportunities were increasingly available to middle- and lower-income groups. Use of public recreation lands continued to increase.

Increased use had its effects, however, and by the mid-1950's, it was apparent that use was overwhelming. Forests, parks and other recreation sites, and the facilities built in the 1930's were deteriorating. Park Service Director Newton Drury responded with Mission 66, a program to rehabilitate facilities and build new ones in the national parks by 1966. Conservationists, led by Joseph Penfold of the Izaak Walton League, recommended additional action to meet the nation's outdoor recreation needs. The result was Congressional action in 1958 establishing the Outdoor Recreation Resources Review Commission (ORRRC). The ORRRC was charged with assessing the nation's outdoor recreation needs to the year 2000 and recommending programs to address those needs. Information was gathered by the Commission over a period of three years.

The ORRRC found that outdoor recreation was a major leisure activity growing in importance and that outdoor recreation opportunities were most urgently needed near metropolitan areas. While considerable land was available for outdoor recreation, it was not effectively meeting the need. The ORRRC's recommendations lead to creation of the Bureau of Outdoor Recreation in 1963 to coordinate national recreation policy and programs. Other results of the ORRRC influence include the Land and Water Conservation Fund (1965), the Wilderness Preservation System (1964), the National Wild and Scenic Rivers System (1968), and the National Trails System (1968).

Outdoor Recreation After ORRRC

In the 1960's and early 1970's, demand for outdoor recreation opportunities dramatically increased again (chapter II). Government at all levels responded to these increasing demands with dollars, land, and facilities. Federal expenditures for recreation increased from \$75 million in 1960 to a high of \$1.4 billion in 1980. In addition to creation of new national wilderness, river, and trail systems, new national parks were established in and near metropolitan areas, along with new national recreation areas within both the National Park and National Forest Systems. The National Wildlife Refuge System also expanded. With money from the Land and Water Conservation Fund, states, cities, and counties expanded their park and open-space systems. Legislation was enacted to reduce air and water pollution and to protect cultural resources. Meanwhile, American society changed significantly. Since 1960, the national population increased by 63 million people and shifted southward and westward; the average American was older; the Nation shifted from dependence on traditional heavy industry to high-technology, communications, and services; and government, business, and residence became less centralized.

The President's Commission on Americans Outdoors

In the 1980's, major changes both in the demand for and the supply of outdoor recreation opportunities became apparent. Participation in many activities had surpassed the projections of the ORRRC. A growing population was putting increased pressure on recreation lands while development was subtracting from available open space in and near growing cities and towns. Technology had spawned a host of new activities, from hang-gliding to driving rugged vehicles off-road, to snowmobiling. The population was changing toward an older citizenry, more women working, and more single parents. The private sector had become a significant supplier of outdoor recreation areas and equipment. Meanwhile, the federal government and many states were in difficult financial straits; they were finding it hard to pay for many programs, including outdoor recreation.

A consortium of interest groups went to Laurance Rockefeller, the chairman of the 1960 ORRRC, and urged that he take the lead in stimulating a new ORRRC-like assessment of outdoor recreation trends and needs. In 1982, Rockefeller convened a small group of conservation and recreation leaders under the chairmanship of Henry L. Diamond, former commissioner of New York State's Department of Environmental Conservation. Revisiting many of the issues the ORRRC had explored 20 years earlier, Rockefeller's Outdoor Recreation Policy Review Group concluded that with governments retrenching, "Even with the tremendous growth in the involvement of the private sector, there is evidence that outdoor recreation opportunities are contracting overall, rather than expanding to meet increasing need." These findings led the Rockefeller group to recommend a comprehensive federal reappraisal of the nation's recreation policy and resources by a new commission patterned after the ORRRC. When efforts to have Congress enact legislation creating the commission stalled, President Reagan established, by executive order, the President's Commission on Americans Outdoors in 1985. President Reagan directed the Commission to look ahead for a generation and determine what Americans wanted to do outdoors and what was needed to ensure that they have the necessary opportunities.

The Commission's report, *Americans Outdoors: The Legacy, the Challenge* (1987), contained more than 60 specific recommendations addressing outdoor education, public services, volunteers, resource protection, information needs, and funding. The Commission said the provision of outdoor recreation opportunities were most needed close to home, and it urged a "prairie fire of local action" to protect, restore, and provide local recreational lands. It recommended the establishment of "greenways" described as "corridors of private and public lands and waters to provide people with access to open spaces close to where they live . . . ." It urged communities to shape growth to keep them attractive places in which to live and work, and it recommended intensified efforts to maintain the quality of natural resources and to increase recreation opportunities on federal lands. Partnerships between government agencies and the private sector were seen as a key to expanding outd[oor] opportunities. Finally, the Commission recommen[ded] that Congress establish a dedicated trust fund to prov[ide] a minimum of $1 billion a year for outdoor recreati[on].

The Protection of Wilderness

The early national parks were intended to provide [a]n outdoor experience in relative comfort—access by tr[ai]n or carriage, plush resorts to which visitors could retr[eat] after a day enjoying spectacular scenery. Within t[he] federal government, the current concept of wilderness[—] land left essentially wild and free from human impac[t—] originated with the Forest Service. In the 1920's, Al[do] Leopold, Arthur Carhart, and others in the Forest Se[rv]ice began advocating the preservation of large areas [in] an undisturbed state. Leopold provided a working de[fi]nition: "A continuous stretch of country preserved i[n] its natural state, open to lawful hunting and fishing, [big] enough to absorb a two-weeks' pack trip, and devoi[d of] roads, artificial trails, cottages, and other works of ma[n]" (Wellman 1987).

The nation's first wilderness preserve, t[he] 500,000-acre Gila Roadless Area in New Mexico's G[ila] National Forest, was designated by the Forest Serv[ice] in 1924. Four more designations quickly followed. S[ub]sequently, the Forest Service developed the "L-20" re[gu]lations, directing national forest staffs to prot[ect] "primitive" undeveloped lands. This represented [o]ne of the first attempts to establish wilderness as a gene[ral] classification of land use with specific managem[ent] guidelines. Under these regulations, some 63 primitiv[e] areas encompassing nearly 8.5 million acres were est[ab]lished. But protection was tenuous, boundaries co[uld] be changed by administrative order, and many contai[ned] state or private lands which were subject to devel[op]ment. Wilderness advocates, especially Robert Marsh[all], then chief of the Forest Service's Recreation and Lan[ds] Division, pressed for stronger measures. The result w[as] the "U-Regulations" of 1939, which established th[ree] land categories: wilderness (areas of more than 100,0[00] acres to be left undeveloped); wild (5,000 to 100,0[00] acres to be managed as wilderness); and recreation (ro[ad]less areas where timber harvest and some other devel[op]ment were permitted).

Following World War II, wilderness proponents, [le]d by Howard Zahnisher of the Wilderness Society, press[ed] for congressional action to provide greater protect[ion] than that afforded by administrative action and est[ab]lishment of a "national wilderness preservati[on] system." With impetus provided by the ORRRC's w[il]derness endorsement in its 1962 report, the Wildern[ess] Act became law in 1964. Passage of the Act created t[he] National Wilderness Preservation System (NWPS) a[nd] requires affirmative action by Congress on each addit[ion] to the wilderness system. It shifted the process of wild[er]ness designation from the Forest Service to Congress a[nd] made it intensely political (Roth 1984). While t[he] Wilderness Act applied to national parks and natio[nal] wildlife refuges as well, its early effects were felt ma[in]

by the Forest Service, which already possessed large reas of protected wilderness. Lands managed by the ureau of Land Management were not subject to the Vilderness Act until passage of the Federal Land Policy and Management Act of 1976. Most early congressional designations were in the West where large, oadless, and relatively pristine areas existed. Wilderness was more problematic in the East where land purchased for national forests had substantial evidence of arlier human settlement. The Wilderness Act of 1975 made it clear that these lands could qualify for wilderness status, too.

In the 1970's, two major inventories of potential ilderness in the national forests were conducted ermed Roadless Area Review and Evaluations, or RARE and II), and the process for considering wilderness esignation in the national forest land management planing process was formalized. Designation remains highly controversial. Nonetheless, almost 89 million acres f wilderness have been established as of 1988, more han 32 million of it in the national forests. Little more han one-third of the NWPS is located in the lower 48 ates. Its eventual size may increase, but the relative distribution in Alaska and the 11 western states will change ttle.

Wilderness Use Today

Accurate assessments of current wilderness use are difficult due to the nature of wilderness. It is very often remote with limited opportunities for user contact. Also, no study of wilderness comparable to the President's Commission on Americans Outdoors has been undertaken. However, several national conferences in the 1980's have focused on different aspects of the recreational and nonrecreational use of wilderness.

Most researchers now conclude that recreational use of wilderness is growing more slowly in the late 1980's, following rapid growth in the prior two decades (chapter II). A number of reasons account for this slower growth including changing age structure and population redistribution, constraints on leisure time, fuel availability and price, and changing interests and preferences. Nevertheless, within the national forest system, 1 of every 20 overnight stays occurs in wilderness.

Yet, on-site recreation activities are not the only valid measure of wilderness use. A number of Americans may value and "enjoy" wilderness without leaving home—through books and films, by just knowing that wilderness exists and could be used in the future, or by knowing the resource will be there for future generations.

Growth of recreational use of wilderness peaked in the late 1970's, after a 20-year period of rapid growth. Interest in nonrecreational values of wilderness has increased in recent years.

Recreation should not be viewed as the only use of wilderness. The value in protecting wildlands for a multitude of reasons has been noted for years by many Americans (chapter II). According to the Wilderness Act, wilderness may also provide the "public purposes of. . .scenic, scientific, educational, conservation, and historical use" (Section 4b). These other values are only now being studied in detail; but, undoubtedly, they will grow in significance, both as they are better measured and valued and as the country becomes more populated and developed.

Because of the nature of some of the nonrecreational values, American wilderness has implications on a global scale. The protection of the environment is no longer simply a national issue. It is international, as the pollution of one nation affects the environmental resources of others. Accordingly, the wilderness in the NWPS benefits more than one nation when it safeguards gene pools, cleans air and water, and helps moderate global climate change.

High-Priority Issues for Outdoor Recreation

High-priority issues have been identified through several means: by special studies conducted for this assessment and the President's Commission; through involvement of key professionals and scientists; through a series of strategic planning sessions involving a broad range of interests; and through a comprehensive review of state outdoor recreation assessments submitted by state recreation agencies. These are discussed below.

Resource protection.—Protection of resources and open space has been identified as the most important issue affecting outdoor recreation. Protection should be viewed in terms of a comprehensive strategy involving the reservation and protection of lands and waters for recreation use and ensuring a high-quality environment in and near recreation areas.

Acquisition of open space.—Most states and recreation interests believe more land and water must be acquired to meet anticipated outdoor recreation needs. Of high priority is the acquisition of land for ocean, lake, and river access. A study of local government professionals shows they identified, almost unanimously, the need to acquire additional space and access (McDonald and Cordell 1988).

Conflicting use.—Conflicts among recreation interests rank highly as an issue of outdoor recreation significance. Most often mentioned are conflicts between hikers and motorized trail vehicles, between motorboats and nonmotorized vessels, between consumptive and nonconsumptive visitors, and between development and preservation interests.

Coordination.—Coordination among public agencies, private nonprofit organizations, and industry must improve. Resources, facilities, and services often can be provided more effectively through partnerships involving public agencies and private organizations.

Access to outdoor recreation.—Access for outdoor recreation by all population groups is a major concern of contemporary America. This includes both phys and social access and it especially pertains to access f disabled and other special populations.

Public information and education.—Public educat is essential to spotlight recreation opportunities, benefits of recreation, and threats to recreation resour Increasingly, Americans come from an urban backgrou with little understanding or empathy toward our na ral environment. Without such understanding, sensi ity to environmental losses or to the many values outdoor recreation is often lacking.

Liability.—The high cost or unavailability of liabi insurance has emerged as a major issue. Liability is eit unavailable or very expensive for local agencies and p vate providers. As a result, some cities have cut back recreation programs while private suppliers are of forced to increase fees to cover the higher cost of ins ance. Moreover, most landowners are reluctant to op their land for public use for fear of costly lawsuits.

Funding.—The need for stable, continuous funding pay for operating and maintaining recreation facilit ranks among the top current issues. Most state and lo agencies strongly favor continuation of the Land a Water Conservation Fund (LWCF) (PCAO 1987). A needed is expanded and more flexible authority to cha fees for use of public lands, especially federal land

Information needs.—More information about the pu lic's recreation preferences is needed to adequately p recreation programs and identify land acquisition nee More information is needed on the values of recreatio on the demand for and participation in various activiti on public and private recreation supply, and on the qu ity of recreation resources and the environment.

High-Priority Issues for Wilderness

High-priority issues have also been identified wilderness through discussions at recent national co ferences (Freilich 1989, Kulhauy and Connor 1986, Lu 1987). These are discussed below:

Allocation.—The appropriate criteria or agenda t determines the final size and composition of the NW is much debated (Reed 1989). Aside from the obvio recreational demand, advocates of increasing the NW point to the need to protect representative ecosystems a areas to monitor environmental changes among ot reasons. Those who argue against enlarging the NW are concerned that wilderness restrictions on water u grazing, mining, and energy extraction do not contr ute to the national economic growth.

Nontraditional wilderness.—A related issue is whet the NWPS should be expanded to include aquatic a underground wilderness units. In addition to amendi the Wilderness Act, a number of potential proble would need to be resolved, including surface rights

Wilderness degradation.—The characteristics imp tant to wilderness are vulnerable. Even the Wildern Act itself sets up a tension between human use a preservation of wilderness character. Some wildern areas are heavily used for recreation resulting in soil e

ion, plant loss, water pollution, disruption of wildlife, and loss of opportunities for solitude. Wilderness is also threatened from outside sources including aircraft overflights, air pollution, and the introduction of exotic plant species. Furthermore, wilderness may be threatened from global influences such as ozone depletion, acid precipitation, deforestation, and desertification.

Nonrecreational use.—Increasing attention is being paid to the range of wilderness values apart from recreation. These values include consideration of habitat, scenic, scientific, educational, conservation, spiritual, and historic uses. Many of these uses have yet to be accurately measured and commensurately valued. As a consequence, many important uses of wilderness may not be well represented in forest and resource planning.

International cooperation.—The National Wilderness Preservation System is unique in the world in terms of its purpose. Yet, it could serve as a component of a larger global system of wild areas for resource protection.

Management coordination and consistency.—According to the Wilderness Act, wilderness is a supplemental purpose in forests, parks, wildlife refuges, and public lands. Because each agency has a somewhat different mission, the management of wilderness areas is not entirely coordinated or consistent. This situation may be further complicated by subsequent wilderness designation acts which often have special provision for only one or two wilderness areas.

Funding and training.—The designation of wilderness by law does not ensure the preservation of an area in its original condition. Inadequately trained wilderness managers and understaffed and poorly funded wilderness management programs seriously hamper the mandated responsibility to preserve wilderness character. In addition, baseline and applied research is in many cases lacking or the results often are not translated into specific management provisions.

Education.—Wilderness managers alone cannot prevent the degradation of the wilderness resource. The public must also understand wilderness values and how to use wilderness with respect and restraint, so it does not lose its character. The development of effective educational and interpretive techniques and material to teach the public low-impact use skills will be a continuing challenge.

Assessment Goals

As the preceding synopsis of outdoor recreation in the United States shows, changes in demands and resources have occurred, especially since World War II. Each year, millions of people use the nation's public lands for outdoor recreation. The Analysis of the Outdoor Recreation and Wilderness Situation in the United States is intended to build upon past studies and to establish a new and better information base on outdoor recreation and wilderness demand and supply. Also, this assessment answers several key questions which will help identify ways to meet demand through the year 2040. Specifically, it is to serve as the foundation for the Forest Service's development of a 50-year program through which that agency can help satisfy the nation's outdoor recreation and wilderness needs.

This assessment will address several questions:

1. What is the current status of outdoor recreation and wilderness resources?
2. What are the nature and magnitude of long-range trends in demand for and supply of outdoor recreation and wilderness resources to 2040?
3. What are the social, economic, and environmental implications of these trends in demand and supply?
4. What are the opportunities for and constraints to improving the management and use of public land resources in order to meet societal goals?
5. Based on analyses of the answers to these questions, what are the implications for forest and range resource programs in the Forest Service?

Findings of this Assessment

This assessment is based on many sources: literature reviews, surveys of visitors to public recreation lands, surveys of landowners and local recreation area managers, and projection techniques.

Presented below is a condensed version of the Assessment's major findings, arranged according to the chapters that follow. Details explaining how these findings were reached are discussed in depth in those chapters and in the references cited.

The Resource Base for Outdoor Recreation and Wilderness

- State and local governments manage over 54 million acres of recreation lands, over 30 million of which are in the East. Over 95% of the 690 million acres of federal recreation lands are in the West.
- Private rural lands open for recreation, other than industry-owned parcels, are declining due to conversion to other uses and to increased closures or more restrictive access policies. About 23% of private land is open to public recreation.
- Federal agencies manage nearly 89 million acres of designated wilderness in the National Wilderness Preservation System. Most acreage is in Alaska (56 million); all but about 5 million of the 32 million acres in the lower 48 states are on national forests. In addition, defacto (wilderness-like) primitive areas exist on federal, state, and private lands.
- More than 7,000 miles of rivers have been designated for inclusion in the National Wild and Scenic Rivers System, over 85% of which are in the West. State-designated significant rivers (for recreation, historic, scenic, or wildlife reasons) number 60,000 miles, over 70% of which are in the East.
- Most downhill skiing capacity is located in the West and especially on national forest lands. Over two-thirds of the nation's cross-country skiing areas are located in the Northeast.

The Demand for Outdoor Recreation and Wilderness

- The rate of increase in participation in some outdoor recreation activities has slowed in recent years. For these activities, increasing use of public recreation areas largely matches the current rate of increase in population. New activities are appearing, however, and are being substituted for some of the formerly most popular activities.
- Extended long-distance vacations are being replaced by more frequent, close-to-home recreation trips, consequently increasing the importance of recreation opportunities near urban areas.
- Participation patterns differ among activities, with some (such as picnicking) showing infrequent participation by a large segment of society while other activities (such as running or jogging) show a frequent participation by a smaller population group. Physically active recreation activities have become relatively more popular.
- Factors which are strongly related to participation in outdoor recreation include the availability of opportunity, age, ability and disability, race, education, and income. Federal and state recreation areas disproportionately serve young- to middle-aged, able-bodied, white individuals who are most often well-educated and in middle-income groups.
- Following the rapid growth in the 1960's and 1970's, the reported rate of change in wilderness recreation visits slowed in the early 1980's to the point where it leveled off or even declined in some areas. This decline was due, in part, to the same general factors influencing outdoor recreation at that time. Since 1986, reported wilderness recreation use has begun to increase again. Wilderness recreation visits account for about 5% of total Forest Service recreation use.
- Interest in nonrecreational values of wilderness, such as scenic, scientific, educational, conservation, and historical uses, is growing as their significance becomes better understood and measured. The "demand" for these uses should increase as our national population grows.
- Wilderness is an important component in global health, serving to cleanse air and water, protect ecosystems and gene pools, and help to regulate world climate.
- The demand for downhill skiing, cross-country skiing, pool swimming, backpacking, visiting prehistoric sites, running and jogging, and day-hiking will grow faster than for other outdoor activities. If the American public were to have all the opportunities wanted and costs of using these opportunities were to remain the same, each of these activities would increase by at least 30% above current levels by 2000.
- Considering the forecasted number of trips, the most popular recreational activities by 2040 will be sightseeing, walking for pleasure, pleasure driving, pool swimming, picnicking, day-hiking, family gatherings, bicycle riding, photography, stream/ lake/ocean swimming, wildlife observation, visiting historic sites, and developed camping.

The Supply of Recreation

- Land-based recreation opportunities are betwee and 15 times more available in various portions the West than they are in the East. Water recreati opportunities are 2 to 8 times more available in t West.
- An increasingly important limitation to the ava ability of outdoor recreation opportunities is acce to private land and water, or to public recreati lands where private properties bar access.
- The public sector is more actively encouraging p vate investment in recreation sites, facilities, a services on public lands. This has stimulated healthy expansion of recreation opportunities public lands.
- Public participation of outdoor recreation is high dependent upon the availability of opportunities opportunities are expanded at the same rates as the recent past, trail and developed-site land opp tunities, stream and lake water opportunities, a developed winter opportunities will grow m rapidly. Motorized land and water opportuniti and undeveloped snow-based opportunities, w grow slowest.
- Management, resource availability, access, and cility needs are likely to be most acute in the E where effective recreation opportunities are lea crowding is the greatest, and private land closu will have the most impact.

How Maximum Preferred Demand Compares to Availability of Recreational Opportunities

- Comparisons of projected supply and demand outdoor recreation opportunities reveal "gaps" some activities. These gaps occur when prefer demand, or the number of trips Americans wou like to take if there were no shortages of opportu ties, is greater than expected supply, or the numb of trips Americans could take given the scarcit of recreational opportunities that would occur w available resources.
- Projected gaps for land-based activities are mu larger than projected gaps for water-based or sno and ice-based activities.
- Land-based activities with the largest project shortages appear to be dispersed activities such day-hiking, wildlife observation, sightseeing, a backpacking.
- Water-based activities with the largest project shortages appear to be pool swimming and no motorized lake and river activities such as rowi canoeing, and kayaking.
- Snow- and ice-based activities with the largest p jected shortages appear to be dispersed activit such as cross-country skiing.

Social, Economic, and Environmental Implications Demand-Supply Comparisons

- The social characteristics of selected multicour communities across the United States can be co

pared with the available recreation opportunities to yield information on social imbalances. In general, Americans who are elderly, less educated, part of a racial minority, economically disadvantaged, disabled, or living in cities have fewer opportunities to participate in resource-based recreation than do others.

- The uneven distribution of opportunities can have adverse social effects including reduced family stability, more crime and juvenile delinquency, less opportunity for social bonding, more social conflict, and slower ethnic and cultural assimilation.
- Increased economic opportunities for the private sector are projected for several categories of recreation. These include investments in developed recreation areas and the provision of associated goods, services, and information. Increased government revenue generated by user fees is expected to be offset by higher management costs for dispersed recreation.
- Impacts on natural systems from most outdoor recreation and wilderness uses are minimal compared to more consumptive uses such as lumbering or mining. Recreational impacts such as soil compaction and erosion are generally local in nature and the greatest damage occurs during the initial use of an area.
- Outdoor recreation and wilderness use can benefit natural systems through improved esthetic quality, greater environmental awareness, and preservation of natural systems. For example, demand for water opportunities has generated pressure on governments and industry to improve water quality in rivers, especially near urban areas.

Opportunities for Meeting Outdoor Recreation Needs

- Many ways exist to close the gap between demand and supply of recreation and wilderness opportunities. Providers can especially make great contributions by better management and protection of existing environments, resources, and facilities.
- Outdoor recreation opportunity providers can reduce the supply-demand gaps by improving services through increasing responsiveness to the public, and through interagency and public-private sector cooperation and coordination.
- Research identifying recreation and nonrecreation benefits of wilderness and development of better methods of measuring and comparing variables can generate additional alternatives to reduce the supply-demand gap.

Obstacles Hindering Attainment of Opportunities

- Obstacles which could block opportunities to narrow the recreation and wilderness supply-demand gap do exist. A major problem is the imbalance between recreation and wilderness land distribution (mostly in the West) and the population distribution (mostly in the East).
- Private landowners are often hesitant to provide access to their land for public use without economic incentives or protection of the uses for which they own the land.
- Insufficient funding, information, cooperation, and coordination among agencies contributes to problems in reducing the recreation-wilderness supply-demand gap.

Outdoor Recreation and Wilderness Program Implications

- National forests near urban areas represent one of the most important opportunities to meet the increasing demand for outdoor recreation closer to people's homes. Better information about these opportunities, partnerships with local government and private entrepreneurs, education of the visitor, facility upgrades, and intensified management can improve opportunities on these national forests.
- Protection of wilderness and wilderness-like areas and enhancing nonrecreational uses should rise dramatically in importance in the management of the NWPS.
- Overcrowding and user conflicts will intensify in the future, especially on eastern national forests. Educating users and managers, redistribution of use concentrations, and greater use of volunteers are needed to help alleviate these problems.
- National forests typically contain special places and features, some of which are unique and irreplaceable. Every forest is special in some way, and the special features and values making them unique need to be protected. This is especially true for wilderness.
- Increasing public access to both public and private properties will be necessary in the future. More exchanges, easements, acquisitions, and partnerships may be needed in the future to provide this access.
- Quality, safety, and convenience will become increasingly important management targets on national forests. Protection of high-quality scenery, better facilities, control of littering and other human impacts, and upgrading of vistas, trails, and services will be demanded by future recreationists.
- Carrying out an expanded mission in providing recreation opportunities and improving wilderness management for the American public will require an expanded and commensurately accelerated and funded recreation and wilderness research program. Particularly needed are improved techniques for intensified management, monitoring wilderness uses, and values, planning, and marketing.
- The major role for the Forest Service and other federal agencies is to manage the recreation estate to provide access to quality recreation opportunities for all who care to participate while maintaining the quality of the resource and facilitating other multiple-use activities.

An Analysis of the Outdoor Recreation and Wilderness Situation in the United States: 1989–2040

A Technical Document Supporting the 1989 RPA Assessment

H. Ken Cordell, John C. Bergstrom, Lawrence A. Hartmann, and Donald B.K. English

CHAPTER I: THE OUTDOOR RECREATION AND WILDERNESS RESOURCE BASE

Introduction

The resource base for recreation includes all lands, aters, and developments which are available to the ublic under any of various circumstances and which ave not been designated for industrial, commercial, sidential, or other such uses to the exclusion of recreion. This available recreational resource base encomasses more than just that part which has been identified nly for recreational purposes. Some lands also are anaged for more than one use, such as for timber, nare preservation, and grazing, as well as for recreation. ome lands have recreation as a dominant but not sole urpose. On other lands, recreation is only incidental- permitted, but it is not excluded. If available under ny of these circumstances, such land and water esources are considered to be a part of the available **ecreation resource base**. This available recreation esource base is a focus of this Assessment.

Wilderness resources include both federally and nonederally designated roadless areas. Of special interest this country's world-renowned National Wilderness reservation System (NWPS). Also of interest are state ilderness systems and those lands designated and reserved in a wilderness-like condition by private oranizations. In addition to designated wilderness, this hapter also considers nonwilderness lands that offer opортunities for the primitive type of recreation typically ssociated with wilderness. Thus, this assessment also ocuses on **wilderness resources** including recreation opортunities on nondesignated lands with wilderness haracter.

In our treatment of recreation and wilderness reources, this chapter examines the status of the land and ater resource base, the condition of protected wilderess, and public accessibility in terms of proximity to oads and population centers and in terms of resource pe, ownership, and regional distribution.

Categories of Recreational and Wilderness Resources

Recreational resources are of three types. **Land Reources** range from the coastal flatlands across prairies the tallest mountain ranges. **Water Resources** include vers, streams, lakes, oceans, and their shorelines. **Snow and Ice Resources** may be viewed as a subset of land and water resources. These resources include recreation areas with sufficient snowfall and temperature conditions to provide winter sports opportunities. We discuss snow and ice separately from land and water resources because they create very different resource management needs.

This assessment arrays recreationally available land and water by degree of remoteness as determined by distance from the nearest road or roadhead passable to a two-wheel drive passenger vehicle. Distance from the nearest road also characterizes resources as recreational environments and distinguishes them according to their level of development since developed facilities are necessarily close to roads. Each resource—land, water, snow and ice—is subdivided into four categories which identify their remoteness or level of development. Wilderness, the most remote category, acknowledges the importance of wilderness for recreation but does not ignore other wilderness uses and values. These other uses and values are examined separately as required by the legislation that established this important designation of public land.

The subdivisions of resource types, or recreational environments, presented in this assessment are described below and in figure 1. Although some types of opportunities associated with each subdivision are identified below, specific activities and opportunities will be examined in more detail in following chapters.

Land Resources

Wilderness and Remote Backcountry Areas are the most primitive and least disturbed land environments. These lands are either designated as wilderness or lie more than 3 miles from a road. Opportunities for solitude and nature-oriented recreation, such as backpacking, are available on these lands. Nonrecreational uses such as scientific study, ecosystem preservation, protection of habitat for threatened and endangered species, and spiritual development are provided by the wilderness resources in this category. **Extensive Undeveloped Areas Near Roads** border wilderness and the most remote backcountry and lie 0.5 to 3 miles from a road. Recreational opportunities in these areas are typically nonmotorized and include such activities as backpack-

ing, nature study, wildlife observation, and primitive camping. **Roaded and Partially Developed Areas** lie within 0.5 mile of a road but outside heavily developed areas. This recreational environment may be federal, state, or private lands within 0.5 mile of road access. Most state forest, park, and fish and game lands are in this category, as are nearly all commercial forests and most nonindustrial private lands. Forest roads and most trails where both motorized and nonmotorized recreational activities occur are in this category. **Developed Land Sites** principally encompass land-based facilities such as campgrounds and picnic areas. Other important developments include golf courses, resorts, and many municipal facilities such as playgrounds and sports fields.

Water Resources

Wild and Remote Waters include primitive, free-flowing streams or remote bodies of water located more than 0.5 mile from a road. River segments designated or under study for inclusion in the National Wild and Scenic River System (NWSRS) are also included, as are wilderness lakes, rivers, and streams. Rafting, trout fishing, and canoeing are typical of recreation occurring in these waters. **Lakes and Streams Near Roads** include all or portions of water bodies without direct road access but which are located within 0.5 mile of a road. These waters include ponds, beaches, and major portions of federal and other reservoirs. Motorized boating, swimming, and fishing are among the principal recreational uses. Water resources which have direct and adjacent road access and which have associated light development, such as parking areas, boat launch ramps, and

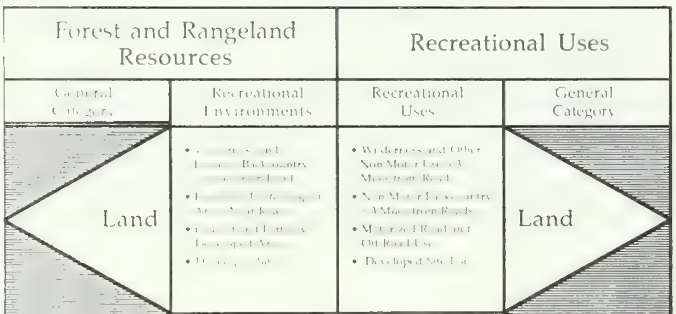


Figure 1.—Categories of recreational and wilderness resources and uses.

scattered picnicking facilities, are discussed in this chapter under the heading of **Partially Developed Water Resources**. **Developed Water Sites** include facilities such as swimming pools, water parks, and marinas. Commercial water-based recreational opportunities are typically within this category.

Snow and Ice Resources

These resources are classified the same as land environments. The distinguishing feature is sufficient snowfall to support a winter recreational season, assumed to be 16 or more inches annually, and temperatures low enough and long enough to freeze the surface of streams and lakes. **Wilderness and Remote Backcountry** winter areas with 16 or more inches of annual snowfall provide opportunities for cross-country skiing, snowshoeing, and activities in solitude at distances greater than 3 miles from roads. **Extensive Areas Near Roads**, 0.5 to 3 miles, and **Roaded and Partially Developed Areas**, less than 0.5 mile from roads, provide opportunities, among other activities, for cross-country skiing, snowmobiling, ice fishing, and sledding. Trails and roads are highly significant to snow- and ice-based recreation. Ski and winter sports resorts characterize intensively **Developed Winter Sports Sites**.

In addition to categorizing recreation resources by remoteness, this chapter also examines who owns or manages them. Thus, privately-owned lands and water are discussed separately from those managed by public agencies. Publicly-owned resources are further subdivided by the level of government managing them. Federally managed resources are discussed first, followed by state-owned resources and, finally, by locally managed resources.

Land Resources

The United States encompasses about 2.4 billion acres including associated water. In 1987, this amounted to almost 10 acres per person, about 1.5 times the world average. Only a very small portion of the total land area is urban or built up—less than 3% nationwide (Bureau of the Census 1987). The federal government manages almost one-third of the country's land; about two-thirds is private. A small remainder is owned primarily by state and local governments. For the most part, the federal estate is undeveloped and uncultivated. Some private lands are developed and some are unaltered from their natural state. The natural forest and rangelands outside federal jurisdictions account for about 35% of our land base, not including Alaska. These public and private lands and water which are available for outdoor recreation are examined in more detail in the following sections of this chapter.

Overview by Ownership

Public land.—One-third of the United States, about 746 million acres, is public land available for recreati-

One-third of the U.S. is public land available for recreation and covers a broad spectrum from small, highly developed local parks to large federal wilderness areas.

Table 1.—Public land and water area (millions of acres) available for outdoor recreation by ownership and region, 1987.

Level of government	Region: North	South	Rocky Mtn.	Pacific Coast	Sub-total	Alaska and Hawaii	Total U.S.
Federal	13.0	17.4	258.7	79.9	369.0	321.7	690.7
State	22.9	6.6	7.8	8.6	45.9	6.7	52.6
Local[1]	1.0	0.5	0.3	0.4	2.2	0.1	2.3
Total	36.9	24.8	266.8	88.9	417.1	328.5	745.6
Percent of area	4.9	3.3	35.8	11.9	56.0	44.0	100.0
Percent of population	47.0	30.9	7.6	13.8	99.3	0.7	100.0

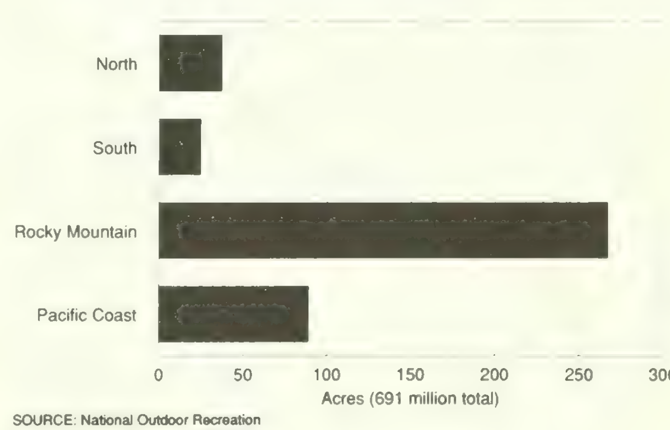
[1]*Includes only local park and recreation departments and other local government properties under the jurisdiction of these departments.*

SOURCE: National Outdoor Recreation Supply Information System, USDA Forest Service, Athens, GA (1987).

This includes about 691 million federal acres, including that under wilderness protection (table 1). All levels of government manage a great diversity of resources, from large undisturbed areas to playgrounds.

Recreation resources are not equally distributed among the levels of government, nor among regions of the country (table 1). Federal agencies manage the majority of primitive areas including wilderness, remote backcountry, and undeveloped forest/land. The western states contain a disproportionate share of these remote public lands mostly because the federal estate is concentrated in the western half of the country (fig. 2). For example, around 70% of Idaho is public land whereas Illinois, with 11 times Idaho's population, is less than 4% public land.

Specially designated federal properties are grouped in four categories (table 2). National Recreation Trails total almost 9,000 miles and are available for a variety of



SOURCE: National Outdoor Recreation Supply Information System (NORSIS) USDA Forest Service, Athens, GA. 1987.

Figure 2.—Area of federal lands in the contiguous 48 states available for public recreation by region, 1987.

Table 2.—Regional distribution of acreages in specially designated federal systems, 1987.

Region	National recreation trails	Wild and scenic rivers	National recreation areas	Wilderness areas
	Miles		*Thousand*	*Acres*
North	2,150	546	285	1,400
South	2,322	366	398	2,500
Rocky Mountains	2,372	1,134	4,093	17,700
Pacific Coast	1,706	5,132	1,147	67,200
Total	8,550	7,178	5,923	88,800

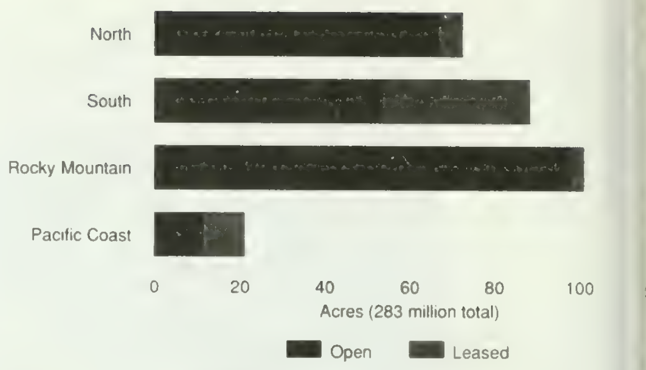
Source: National Outdoor Recreation Supply Information System, USDA Forest Service, Athens, GA (1987).

recreational uses. Wild and Scenic Rivers total over 7,000 miles and are protected from development in order to preserve their outstanding beauty and wildness. National Recreation Areas total almost 6 million acres and are managed mostly for recreation. The National Wilderness Preservation System totals almost 89 million acres and is preserved in a natural condition. Low impact recreation is only one of the NWPS's permitted uses.

States manage about 53 million acres of land available for recreation. State forests generally encompass the more primitive and remote of these lands while state parks offer more developed environments. More than 40% of the 10 million acres of state parks and reserves and over 60% of state forests are in the eastern half of the country. A few eastern states have brought large tracts of wild lands into the public domain, compensating to some extent for the relatively small amount of federal lands there. In general, state lands are much more effectively located for recreation than are federal lands.

County and municipal lands available for recreation, about 2.3 million acres, account for less than 0.5% of the total public recreation domain. Local governments generally have the most intensively developed resources, and they are close to or within populated places and are very accessible. Local resources may be small, but municipal parks account for more than 60% of the number of recreation areas nationwide, illustrating their greater effectiveness in providing some types of public recreational opportunities (President's Commission on Americans Outdoors 1987).

Private land.—Rural private land makes up over 60% of the contiguous United States land base, approximately 1.28 billion acres. Ninety-five percent of this acreage is in nonindustrial ownerships. Currently, more than 350 million acres of nonindustrial private land are closed to all but the exclusive use of owners. Thus, about one-third of nonindustrial private land is not available for public recreation. Access to another 556 million acres was estimated to be restricted to persons who were personally acquainted with owners. These restricted or partially-restricted lands provide an important recreational resource for many, but only about 23% (283 million acres) of nonindustrial, privately-owned rural land is open to the general public for recreation. More than



SOURCE:--National Outdoor Recreation Supply Information System, USDA Forest Service, Athens GA 1987

Figure 3.—Acres of nonindustrial private land open or leased for recreation by region, 1987.

80% of this is open free of charge or for a daily fee. The rest is available through exclusive lease agreements involving either a seasonal or annual fee. The average fee per acre in 1986 was $2.97, about $89 per lessee. Much of this open land is located in the South and in the Rocky Mountains (fig. 3). Since 1977, the percentage of private, nonindustrial lands open for public use has decreased from over 29%[1] to 23%. This represents a decrease of nearly 75 million acres of potential recreational land, mostly in the East.

The private sector provides a full spectrum of land resources, from the remote and pristine to the highly developed, including about 60% of all campgrounds in the United States. Privately-owned recreation resources, and especially undeveloped private lands, may become more important in this country for meeting the increasing demand for many types of outdoor recreation. Typically, these private lands are effectively located near population concentrations, are easily accessible by vehicle, and contain many miles of trails and unimproved roads. However, the strong trends toward closing these acreages to public access, conversion to urban uses (about 1 million acres per year), and subdivision into smaller tracts may seriously reduce their value as a recreational resource in the future.

Recreational Lands by Remoteness

Remoteness, that is, distance from roads, significantly influences the character of a recreation environment and determines its accessibility. The following discussion of land resources is organized around the remoteness criteria as described above and in figure 1.

Wilderness and remote backcountry.—Designated wilderness must be distinguished from other remote wild areas. Wilderness status typically results from legislative action which, in effect, prohibits many uses. The mandates under which other remote backcountry areas are managed generally are not as restrictive. Moreover, the increased publicity generated by wilderness designation can change and increase the recreational use of

[1]*This figure does not include leased acreage.*

and interest in an area, sometimes resulting in needs for greater management attention (Kelly 1989).

Federal wilderness.—The Wilderness Act of 1964 empowered Congress to set aside wild federal lands as parts of the National Wilderness Preservation System (NWPS). As of January 1, 1988, some 88.8 million acres had, thus, been protected. Wilderness areas are among the most pristine and undeveloped lands in the federal estate. Other large, nonroaded tracts of remote federal lands exist, some of which are under study for inclusion in the NWPS.

The original language of the 1964 Wilderness Act emphasized lands which had been left undisturbed by human actions. Few eastern forests met the Act's wilderness criteria. In 1974, the so-called "Eastern Wilderness Act" changed the eligibility criteria by adding to the NWPS some 207,000 acres of eastern lands which had, at one time, been cut over, roaded, or settled, but which had subsequently returned to an apparent natural state. This new flexibility in defining "wilderness" contributed to expansion of the federal wilderness system in the East (Reed 1989).

Since 1964, public lands designated as wilderness have expanded ten-fold. Wilderness distribution within the United States is tied to the existing pattern of federal land within the national forest, park, and wildlife refuge systems and Bureau of Land Management (BLM) lands. At present, designated wilderness may be found in every state except Connecticut, Delaware, Kansas, Iowa, Maryland, and Rhode Island (and the District of Columbia). Alaska leads all states in total wilderness acreage with 56.4 million acres, almost two-thirds of the NWPS acreage.

Because the majority of federal land is in the 11 western states and Alaska, the five-state Pacific Coast Region has three-fourths of the NWPS acreage (67.1 million acres) (fig. 4, table 3). Another 20% (17.8 million acres) is found in the 11-state Rocky Mountain-Great Plains Region. Of the NWPS acreage, 3% (2.5 million acres) is located in the Southern Region and only 2% (1.3 million acres) is in the Northern Region.

The National Park Service (NPS) manages the most wilderness, more than 36.7 million acres (about 41% of the NWPS), which is mostly in Alaska (fig. 5, table 3). The Forest Service is the second largest manager of wilderness with more than 32.3 million acres (36% of the NWPS acreage). The Fish and Wildlife Service (FWS) manages 22% of the NWPS acreage, and BLM wilderness represents 1%.

More than 53% of NPS lands are in wilderness status. Almost 24% of the National Wildlife Refuge System is wilderness. Wilderness status has been given to 20% of the National Forest System and less than 1% of the remaining public lands. The Forest Service manages 83% (26.9 million acres) of the wilderness acreage in the conterminous states.

Wilderness areas range in size from the 8.7 million-acre Wrangell-St. Elias Wilderness in Alaska to the 6-acre Pelican Island off the Florida coast. The average size is nearly 195,000 acres. More than half are between 5,000 and 50,000 acres. About 16% are smaller than the minimum 5,000-acre size recommended in the original Wilderness Act. Less than 4% of all wilderness areas are larger than 1 million acres, and most of those are in Alaska (Reed 1989).

Because of the vastness of Alaska's wilderness, the most predominant ecoregion represented in the NWPS is tundra (27%), followed by subtropical (24%), subartic (18%), and steppe (14%) (Bailey 1980, USDI FWS 1982).

Table 3.—National Wilderness Preservation System by region and agency (in thousands of acres).

Region	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Mgmt.	Total
North	1,163	133	64	0	1,360
South	619	1,444	470	0	2,533
Rocky Mountain	16,576	690	120	330	17,716
Pacific Coast:					
Alaska	5,453	32,356	18,678	0	56,487
Other	8,541	2,137	1	39	10,718
Total	32,352	36,760	19,333	369	88,814

Source: National Outdoor Recreation Supply Information System, U.S. Forest Service, Athens, GA (1987).

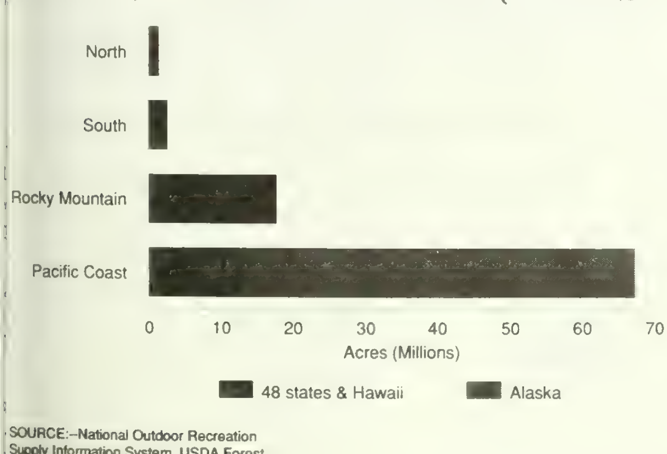


Figure 4.—Acreage in the National Wilderness Preservation System by region.

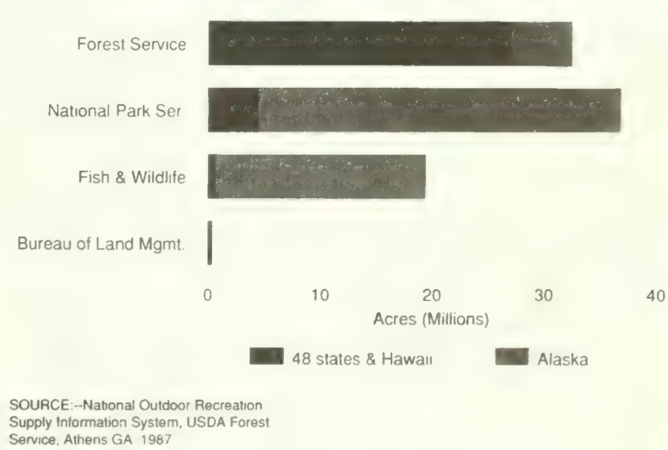


Figure 5.—Acreage in the National Wilderness Preservation System by federal agency.

Particularly under-represented in the NWPS are the prairie grassland ecoregions of the Great Plains (Reed 1989).

Hill and mountain landforms (Hammond 1970, USDI FWS 1982) account for about three-fourths of all wilderness areas. Plains and tablelands make up less than 5% of the NWPS (Reed 1989).

Potential and substitute wilderness lands.—Under the NWPS, 14 million additional acres of federal lands have been recommended for wilderness designation (Reed 1989). Of these recommended areas, 9 million acres are in national parks, 3.4 million in the FWS lands, and 2.4 million are in the national forests. Over two-thirds of this recommended wilderness acreage is in the Rocky Mountain Region; none of it is in Alaska.

Estimates show that approximately 123 million acres of federal lands have been under study at one time or another but are not yet recommended for inclusion in the NWPS (Reed 1989). Another 30 million acres of other public and private lands may also meet the remoteness criteria of wilderness (Absher et al. 1989). These lands outnumber actual NWPS acres by nearly two-to-one. The Forest Service manages about 47% of these potential wilderness lands. Because most federal lands are located in the 11 western states, existing wilderness patterns would be maintained if more areas were designated in the future. Over half of the potential areas are located in the Rocky Mountain Region; only 3% are in the North.

The anticipated trend is for potential wilderness acres to diminish through two opposing processes (Cook and English 1989). First, a portion of those lands currently under study for wilderness classification will eventually be added to the NWPS system. The potential wilderness areas will be further diminished through future development. Some federal roadless areas released from wilderness study for other uses will undergo development or modification that will disqualify them from future consideration for wilderness designation.

In addition to the NWPS, a number of federal wildland preservation systems preserve an additional 12 million acres (Soper and Humke 1989). Complementary to the system in purpose, these other areas similarly seek to ensure natural diversity and generally are not recreation oriented. They include research natural areas, areas of critical environmental concern, special interest areas, and wild rivers in the National Wild and Scenic River System.

Research natural areas are managed to ensure natural diversity and may be designated and managed by any of the four wilderness managing agencies, plus the Department of Defense. Presently, more than 500 research natural areas totalling 4.2 million acres have been established (Soper and Humke 1989).

The Bureau of Land Management manages more than 280 units as Areas of Critical Environmental Concern (ACEC) totaling some 5.1 million acres (Soper and Humke 1989). ACEC's are mandated to protect important historic, cultural, scenic, and/or natural values.

The Forest Service manages 45 special interest areas to protect them and manage their scenic, geological, botanical, zoological, paleontological, archeological, and other special characteristics (Soper and Hum 1989).

Nonfederal wilderness.—Specifically designated n federal wilderness and other wild and natural a constitute approximately 4.9 million acres across country (Cook and English 1989). About 40% of area, in 3,800 separate tracts, is owned by nonpr organizations, 30% is owned by states, and the res private. Only 37 tracts are over 25,000 acres, and are at least 5,000 acres, the minimum size guidelin the original NWPS legislation. About 72% of these ac in large tracts are state lands. In general, the preser tion efforts of states and other nonfederal entities se to have complemented the distribution of NWPS la because they are concentrated in the East (table 4)

About one-fifth of the states have wilderness pres vation systems. State wilderness and wild area crit are similar to the NWPS criteria in many ways. Sta have often adopted the language of the federal wild ness act, incorporating varying degrees of flexibility their definition of wilderness (Stankey 1984). Penns vania, for example, allows old roads and utility righ of-way through state wilderness areas. New Yor Adirondack Mountains equal or surpass the wildn scenic quality of any NWPS area in the East, and Mi igan's Porcupine Mountains Wilderness State Park co tains the second largest virgin forest in the East, a the Adirondacks (Crispin 1980). The distribution state-owned wilderness varies across the country (ta 4). The North and the South contain more than tw thirds of all state-owned wilderness, illustrating h states have an opportunity to compensate, to some tent, for the large area of federal wilderness in the We

Most states with large, roadless tracts have alrea reserved some portion of them in a wilderness syste States with large state forest systems have the option removing further portions to wilderness status, but t seems unlikely (Cook and English 1989). Natural are on the other hand, are increasing through stepped- acquisition by nonprofit organizations, private la trusts, and the like (Nutter 1984). Rapid growth beyo their present acquisitions are unlikely, however, becau of a dwindling base of large natural areas.

Several nonprofit organizations and institutio including local governments, own or protect wild

Table 4.—Acres of state-owned wilderness and extensive roadless ar (in thousands of acres), by managing agency and region, 198

Region	Agency		
	State forests	State parks	To
North	2,292	31	2,3
South	0	99	
Rocky Mountains	0	49	
Pacific Coast	10	2,539	2,5
Total	2,302	2,718	5,0

Source: National Outdoor Recreation Supply Information System, US Forest Service, Athens, GA (1987).

natural areas. In most cases, these places are set aside primarily to preserve unique or critical ecosystems and wildlife habitats, and not necessarily to provide recreation. These areas are included as recreation resources because they attract visitors and may accommodate low-impact recreational pursuits such as hiking or nature study. Such areas provide trails and parking but generally few other amenities.

Other federal remote wild lands.—The federal government manages just over 100 million acres of nonwilderness but remote lands, about 70 million of which are in Alaska (English 1989). Much of the remainder are BLM lands in the West. Outside Alaska, the Forest Service manages just 1.5 million of these acres. Only 1.4 million acres of remote and roadless areas exist in the East (table 5).

State remote wild lands.—About 5 million acres of state lands are in wilderness or remote backcountry (English 1989). State park systems include 75% of these lands. The rest are state forest lands, almost all of which are in the North. Over half of the remote acres managed by state park systems are in the Southern Region while most of the rest are in Alaska. The Rocky Mountain Region contains little remote state land because of the vast federally-managed acreage in this part of the country.

Extensive undeveloped areas.—Surrounding wilderness and the most remote backcountry lies a class of lands located between 0.5 and 3 miles from road access. Presumably, 0.5 mile is a sufficient buffer to impart a remote character to the land.

Federal lands.—More than 86% of the 87.3 million acres of lands in this undeveloped category are part of the National Forest System (table 6). Another 12% are in national parks. The majority of these large, undeveloped areas are located in the Rocky Mountain Region. About 2.2 million acres are located in the North, and another 3.3 million acres are in the South. The East has about as much land in this category as it does in the two more remote categories combined.

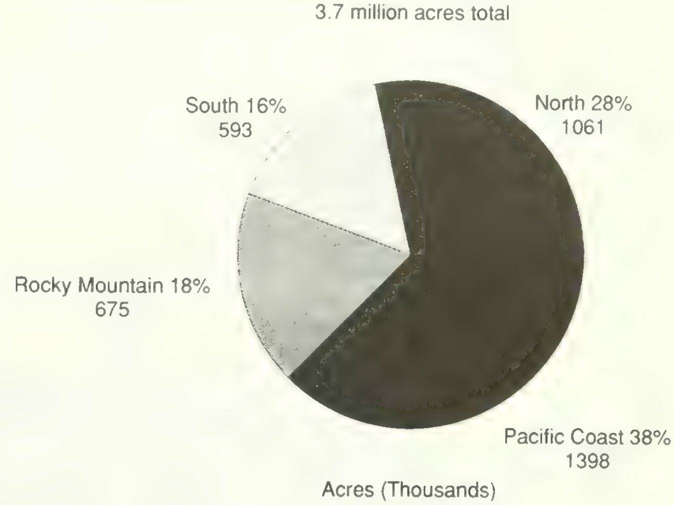
State lands.—State-owned lands provide about 3.7 million acres of backcountry lands between 0.5 and 3 miles from roads—all on park system properties. Over one-third of these acres are in the Pacific Coast Region, and over one-fourth are in the North (fig. 6).

Nonindustrial private lands.—An estimated 31 million of the 283 million acres of open private rural lands are more than 0.5 mile from a road and are extensive enough to be placed in this category. The vast majority of this private backcountry acreage is in the Rocky Mountain Region—almost 26 million acres. About 3.5

Table 5.—Distribution (in thousands of acres) of federal remote backcountry, not in the NWPS, greater than 3 miles from a road, by region.

Region	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Mgmt.	Total
North	0	605	18	0	623
South	0	596	217	0	813
Rocky Mountain	1,539	1,863	117	14,725	18,244
Pacific Coast:					
Alaska	11,910	11,996	46,826	0	70,732
Other	0	1,596	0	9,922	11,518
Subtotal	11,910	13,592	46,826	9,922	82,250
Total	13,449	16,656	47,178	24,647	101,930

Source: National Outdoor Recreation Supply Information System, USDA Forest Service, Athens, GA (1987).



SOURCE: National Outdoor Recreation Supply Information System (NORSIS), USDA Forest Service, Athens GA, 1987.

Figure 6.—State recreation lands between 1/2 and 3 miles from a road by region, 1987.

Table 6.—Distribution (in thousands of acres) of federal extensive undeveloped areas, by region and agency.

Region	Forest Service	National Park Service	Fish and Wildlife Service	Bureau of Land Mgmt.	Tennessee Valley Authority	Total
North	2,011	139	38	0	0	2,188
South	1,602	1,512	145	0	6	3,265
Rocky Mountain	53,227	5,907	243	736	0	60,113
Pacific Coast	18,703	2,731	3	318	0	21,755
Total	75,543	10,289	429	1,054	6	87,321

Source: National Outdoor Recreation Supply Information System, USDA Forest Service, Athens, GA (1987).

million of the backcountry acres in the Pacific Coast region are leased for recreational use.

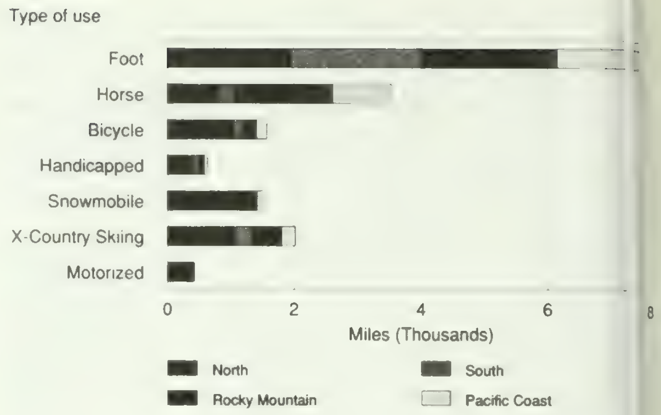
Roaded, partially developed lands.—The land areas most heavily used for outdoor recreation are those within 0.5 mile of or adjacent to roads. Most trails, often former access roads or rail lines, lie within this distance of current roadways and often parallel or cross them. The majority of lands outside the federal estate are in this category. Intensively developed sites located near roads will be discussed below under "developed lands."

Federal lands.—More than half the entire federal estate, nearly 390 million acres, is located within 0.5 mile of a road and is outside intensively developed areas, such as campgrounds. Almost 80% of this acreage is managed by the BLM. The Forest Service manages nearly all the remaining 72 million acres, only 5% of which are located in the eastern half of the country. Nearly 50% of federal lands in all regions, except the Pacific Coast, are in this category. Due to the extensive roadless areas in Alaska, less than 20% of federal lands in the Pacific Coast are within 0.5 mile of a road.

Among the most important of resources within roaded, partially developed areas are trails for walking, biking, horseback riding, and other trail-dependent activities. Federal agencies manage about 160,000 miles of trails. Nearly 100,000 are on Forest Service lands, and about 36,000 are on BLM lands. Although the majority of these trails are located in the western regions, federal agencies still provide 23,000 miles of trails in the eastern half of the country. Through federal agency efforts, coordinated by the NPS, over 760 trails and trail segments covering over 8,400 miles have been designated as part of the National Recreation Trails System (NRTS). Over 500 of these trails are managed by federal agencies, about 140 by local governments, 80 by state agencies, and almost 30 by private individuals or organizations. Figure 7 shows the regional distribution of NRTS trails by use type.

State lands within 0.5 mile of a road.—About 80% of state recreation lands, 43 million acres, are relatively undeveloped and lie within 0.5 mile of roads. Just over one-half are managed by forest agencies; most of the rest are under the jurisdiction of park or fish and game departments. The North contains over one-third of all such state lands, about two-thirds of this area is managed by forest agencies (fig. 8). State agencies manage about 102,000 miles of trails. Over half of these (57,000 miles) are in the North, and about one-third (38,000 miles) are in the South. Fewer than 10,000 miles are located on state lands in the western half of the country.

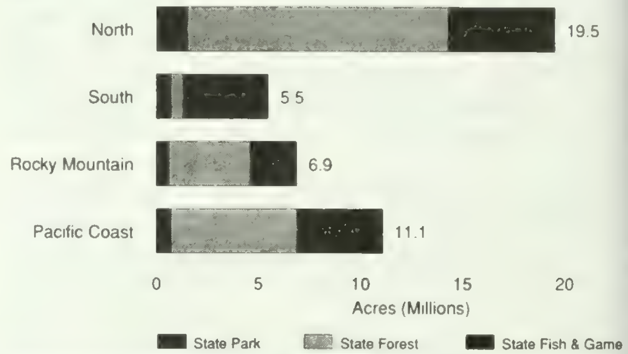
Privately owned roads and trails.—Approximately 2.3 million miles of roads and trails (15% of the 15.5 million total miles) are located on nonindustrial private land open to the public for recreation (fig. 9). This represents about 1 mile of trail or unimproved road per 123 acres of private land designated by owners as open to public access. Lands in the East appear to be more heavily roaded than lands in the West. The North has over 1 million miles of roads and trails on private lands compared to about 300,000 in the Rocky Mountain Region and about 121,000 in the Pacific Coast. Many private roads



SOURCE: National Outdoor Recreation Supply Information System (NORSIS), USDA Forest Service, Athens GA, 1987.

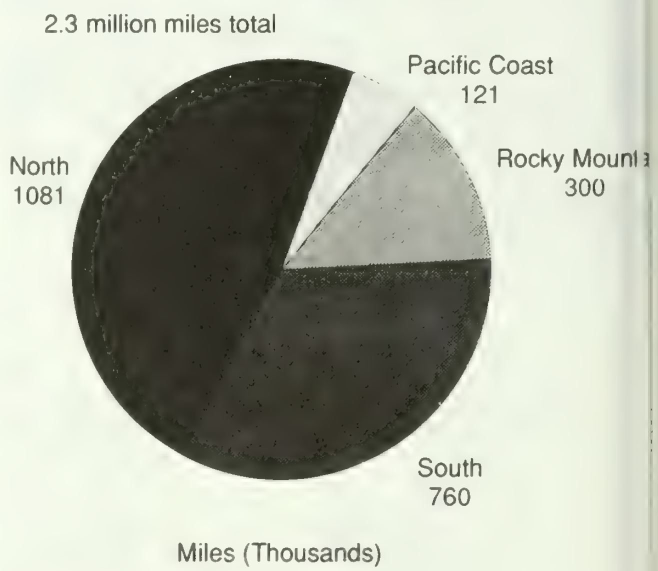
NOTE: Trail miles are not additive uses due to designations for more than one use.

Figure 7.—Miles of National Recreation Trails by region and of use, 1987.



SOURCE: National Outdoor Recreation Supply Information System (NORSIS), USDA Forest Service, Athens GA, 1987.

Figure 8.—State recreation lands within 1/2 mile of a road by re n and jurisdiction, 1987.



SOURCE. National Outdoor Recreation Supply Information System (NORSIS), USDA Forest Service, Athens GA, 1987.

Figure 9.—Miles of roads and trails on nonindustrial private la open to the public for recreation.

are not maintained and, thus, are not clearly distinguishable from trails.

Developed land sites.—Man-made facilities such as golf courses, campgrounds, and amusement parks as well as developed areas designed for very intensive uses such as playgrounds, ballfields, and picnic areas form the "developed lands" category. These lands are the least remote, generally adjacent to roads, and very often located close to or within populated areas.

Campgrounds.—Campgrounds range from the rustic—a fire pit and a flat place to pitch a tent—to full-amenity sites with hot showers, tables, electrical and sewer hookups, and sometimes cable television and telephone hookups for recreational vehicles. Campgrounds are an ever-present component of the American outdoor opportunity. As a recreational resource, they concentrate on human use, are hardened to withstand environmental impact, and provide launch points for trips into natural areas or to nearby attractions of great variety. Over 17,000 are listed and include over 1.3 million campsites across the country.

About 5,000 of the campgrounds in the United States are operated by eight different federal agencies. The majority, 70%, are in national forests. The Corps of Engineers, the second largest supplier, manages another 17%. In terms of regional distribution, the Pacific Coast and Rocky Mountain Regions split equally 70% of all federal campgrounds. Only 10% of federal campgrounds are located in the North. Generally, federal campgrounds are less developed than their state and commercial counterparts. Nationwide, less than 10% of federal campgrounds have water, electrical, or sewer hookups.

Nationwide, state agencies manage almost 2,100 campgrounds, mostly in state parks, with 134,000 spaces. State campgrounds are concentrated more in the eastern regions, particularly in the North. Often, these campgrounds provide accommodation for visitors who come primarily to use the lakes which are frequently found in state parks.

The private sector accounts for about 55% of all campgrounds in the U.S. and provides more than 70% of the total capacity. In general, private campgrounds cater to the camper who desires more facilities and services than public campgrounds provide. Private campgrounds, more often than public ones, provide amenities such as a store, hookups for water, electrical, cable TV, and phone, and playground facilities. Over 50% of private campgrounds nationwide provide full hookups (McEwen 1989).

Just as states have at least partially compensated for the regional concentration of federal wilderness lands in the West, private enterprise in the East provides camping opportunities where a much greater proportion of the population resides. The North has more than 40% of private campgrounds; the South has another 30%. The greater concentration of public lands in the West accounts for the greater proportion of public campgrounds in those regions (fig. 10).

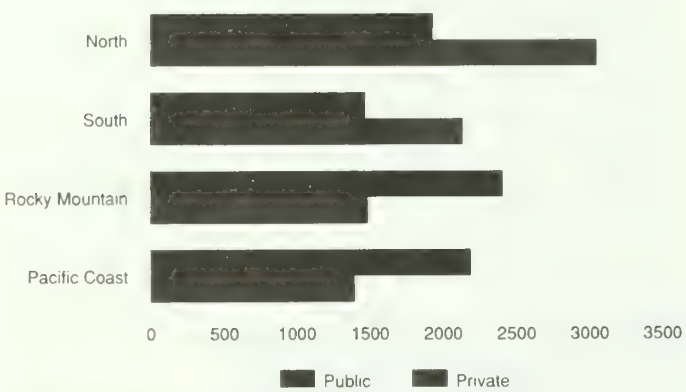
Roads.—As the automobile continues to shape the American lifestyle, driving for pleasure continues to rise as a pastime. Roads are an important part of the national recreation resource base. Federal agencies manage about 144,000 miles of roads on federal lands that are available for recreation as well as for other uses. Their regional distribution parallels the distribution of federal lands. The North and South Regions combined contain fewer roads on federal lands for recreation than the Rocky Mountain Region alone (fig. 11). Few roads on federal lands are designated specifically for recreational uses as is, for example, the Blue Ridge Parkway.

The over 17,000 campgrounds in the U.S. range from the more rustic federal sites to full-amenity campgrounds, mostly privately owned. Seventy percent of federal campgrounds are managed by the Forest Service.

Nonetheless, these roads are vital to access as well as recreational opportunities in themselves. In the mid-1980's, the recreational importance of roadways was recognized in the various scenic byway programs being initiated as a combined effort of state and federal agencies. These programs are expected to bring emphasis to the aesthetic qualities of highways and their surroundings.

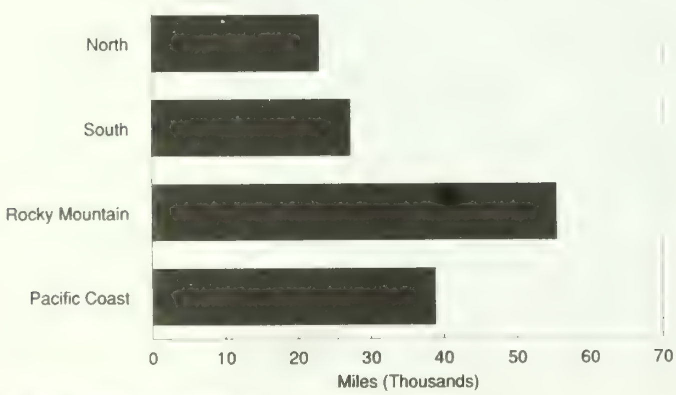
Other developed recreational resources.—A large portion of the facilities developed for recreation were built and managed by the private sector, but several important public sector contributions exist. Federal agencies operate over 63,000 picnic areas, 80% of which are located in the East. State-run picnic areas, which generally are provided at state parks and recreation sites, are similarly distributed due to the concentration of these areas in the North.

Dude ranches and golf courses are among the myriad commercial enterprises operated by independent entrepreneurs and large developers. Generally, such private businesses provide resources and services not otherwise available. Often, they facilitate access to public areas. The majority of land-based commercial enterprises are located where the population is most dense. Almost



SOURCE: National Outdoor Recreation Supply Information System (NORSIS), USDA Forest Service, Athens GA, 1987.

Figure 10.—Number of public and private campgrounds by region, 1987.



SOURCE: National Outdoor Recreation Supply Information System (NORSIS) USDA Forest Service, Athens GA, 1987.

Figure 11.—Miles of road on federal land open for recreation, by region, 1987.

three out of five resident camps are located in the Nor a region which also contains nearly half of the countr 11,000 commercial resorts. Another 18% of resorts located in the South.

Three-fourths of the more than 6,000 golf courses op to the public are located in the East. The 2,400 membe only golf courses are also located primarily in regic with the greatest population. Golf courses also provi an important open space resource where people wa jog, ski, snowshoe, or participate in other compatil activities.

Local lands.—As noted in the introduction to this se tion, the numerous local recreation areas are small i area but large in numbers and use. More than 75% c American adults use local parks or other recreation faci ities in their communities. Over 7,000 local park a recreation departments serve local communities, a they manage about 2.3 million acres of recreation lan in over 94,000 separate areas. Primarily, local gove ments provide developed resources for intensive structured recreational use. About 85% of the depa ments provide about 64,000 sports fields and 44,(playgrounds. About two-thirds of these local gove ment agencies provide outdoor tennis (57,000 cou nationwide) and basketball (23,000 courts), and ab half provide fitness trails and volleyball courts. Lo governments also provide almost 6,500 outdoor sw ming pools, 1,500 18-hole golf courses, and over 8 9-hole golf courses (fig. 12).

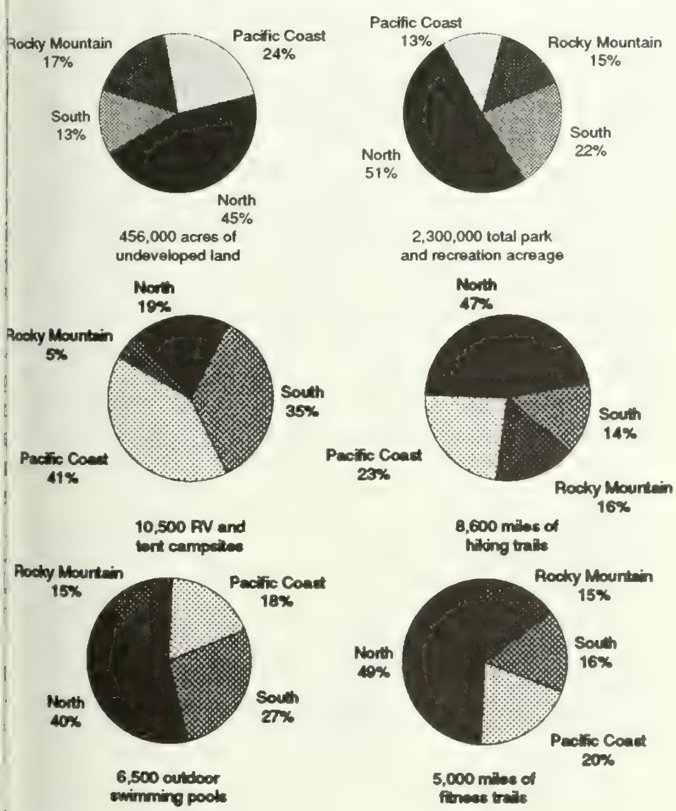
Undeveloped natural resources are also managed t many local park agencies. A nationwide survey of c and county governments showed that, out of all lo recreation land holdings, more than 400,000 acres, about 18% of the total, were in an undeveloped st (McDonald and Cordell 1988). Nationally, about hal all local park agencies manage natural areas of wh about half are at least 100 acres. The larger the popu tion served, the more likely that a local departm manages some natural area acreage and the larger t department the larger the total area is likely to be.

Of the 7,000 local park and recreation departme nationwide, 63%, about 4,500 departments, mana recreational trails. Local trails total about 27,000 mi nationwide (fig. 12). Most of these trails are manag as fitness trails (46% of departments), hiking tra (29%), or bicycling trails (21%). A small percentage trails are managed for off-road vehicle use (3%). T total mileage in hiking trails exceeds 8,500, with 6,8 bicycle trail miles, 5,000 fitness trail miles, over 5,0 snow trail miles, and 470 miles of off-road vehicle tra Other types of trails total about 2,500 miles.

Local governments also operate overnight camp facilities. Nationwide, recreational vehicle and t campsites number more than 10,000 (fig. 12). There also approximately 10,500 day and resident camp ar operated by municipal and county governments.

The almost 2.3 million acres of local government p and recreation lands do not tell the whole story. Ma more local lands contribute indirectly to recreati through local open space acquisition programs. Lo agencies were reported to administer 8.7 million ac

Over 7,300 river miles in over 720 rivers have been designated as wild, scenic, or recreational rivers.



SOURCE: National Outdoor Recreation Supply Information System (NORSIS), USDA Forest Service, Athens GA, 1987.

Figure 12.—Selected local park and recreation land facilities by region.

of open space in more than 87,000 separate units across the country in 1986 (President's Commission on Americans Outdoors 1987).

Water Resources

As with land resources, water resources vary from primitive to highly developed, from remote, alpine lakes to highly developed marinas. Water resources are managed by a variety of public agencies at all levels as well as by the private sector. As with land resources, the private sector contributes at the more developed end of the resources spectrum. Because access to water resources frequently requires facilities of some sort, private enterprise contributes most heavily by providing commercial access sites.

Wild and Remote Waters

Federal waters.—Of the nearly 3.6 million miles of rivers and streams in the United States, 7,365 miles in over 720 rivers or river segments have been designated as wild or scenic rivers under the Wild and Scenic Rivers Act of 1968. These rivers constitute the National Wild and Scenic River System (NWSRS). The NWSRS was established to protect free-flowing rivers with scenic, recreational, or other distinctive values. Rivers are classified as "wild," "scenic," or "recreational" depending on their accessibility, extent of disturbance to the river and surrounding area, and the degree to which they

provide outstanding scenic or recreational opportunities. Most such designated rivers are managed by the federal government, but about 10% are managed by state or local governments, sometimes in partnership with a federal agency.

Rivers and river segments in the NWSRS include some of the most remote waters in the country. As with wilderness, most wild and scenic river miles are located in the West, specifically in the Pacific Coast Region (71%) which includes Alaska. A little over 900 miles (13%) of wild and scenic river miles are located in the East.

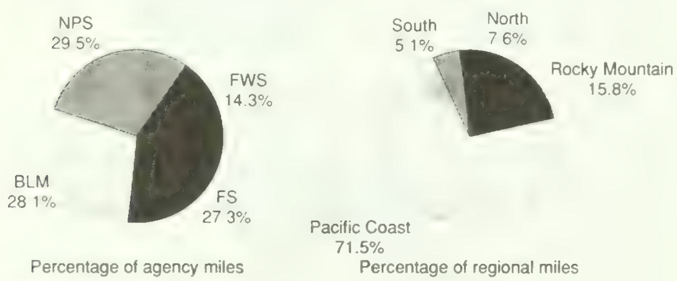
Almost 7,550 additional miles of river are, or have been, under study for possible inclusion in the NWSRS. Most of these segments are administered by the NPS. Unlike the already designated mileage, these segments are distributed fairly evenly across regions. In the East, four times as many miles of rivers are under study as have been designated wild and scenic rivers. Compared to the distribution of wilderness lands, the eastern regions contain a larger share of this fairly primitive resource (fig. 13).

Undeveloped state waters.—Many states protect rivers or sections of rivers which are largely free-flowing and undisturbed. More than 60,000 miles of rivers fall into this category. The eastern half of the country contains more than 70% of these state-managed, undeveloped rivers.

Partially Developed Water Resources

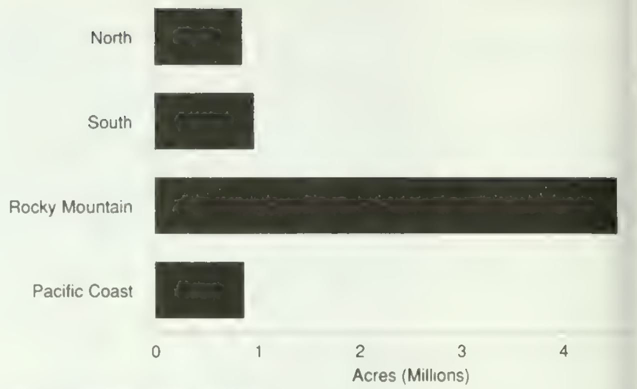
A number of federal agencies manage water resources adjacent to road access. These areas include lake and ocean shorelines and rivers with road and parking access at the water's edge or crossing it. The estimates of resources in this category include portions of national rivers, seashores, lakeshores, and recreation areas, as well as river miles on land managed by the BLM and water areas and lakeshore miles on lands managed by the Corps of Engineers, the Tennessee Valley Authority, and Bureau of Reclamation. The information in this category is mostly for federal resources. Information on surface water acreage that is partially developed and owned by states was not available.

More than two-thirds of this partially developed water resource is located in the Rocky Mountain Region (fig. 14, table 7). While the North has the fewest acres of par-



SOURCE: National Outdoor Recreation Supply Information System (NORSIS), USDA Forest Service, Athens, GA, 1987.

Figure 13.—Distribution of miles of National Wild/Scenic River components by agency and region as of January 1, 1987.



SOURCE: National Outdoor Recreation Supply Information System (NORSIS) USDA Forest Service, Athens, GA. 1987

Figure 14.—Acres of National Rivers, National Recreation Ar[...], National Seashores, and National Lakeshores, 1987.

tially developed water, most are near major metrop[...] tan areas, facilitating access by large groups of peo[...] The Rocky Mountain Region dominates in this categ[...] because most Bureau of Reclamation projects are loca[...] there. About 40% of municipal recreation departme[...] manage lake areas for recreation, over 56,000 total ac[...] and about half of these lakes are at least 15 acres in si[...]

Developed Water Resources

The private sector is the largest provider of develo[...] water resources. Federal and state developments gen[...] ally are less developed and more closely linked to [...] natural resource base than are commercial enterpri[...] and local facilities.

Swimming areas, beaches, and boating.—Counte[...] the prevailing pattern of other types of federal rec[...] tion areas, water resource facilities are concentrate[...] the eastern half of the country, particularly in the Sou[...] This is primarily due to the large number of facili[...] operated in the East by the Corps of Engineers and [...] Tennessee Valley Authority. Many developments ar[...] large that extensive partially developed areas co-exist [...] the same reservoir with scattered developed sites. [...] mentioned above, these types of facilities also ten[...] be near population centers because of historic settlem[...] patterns along river corridors in the East.

The percentage of state parks providing swimm[...] and boating gives an indication of the developmen[...] water resources at the state level. A greater proport[...] of state parks in the Rocky Mountain Region prov[...] these types of resources than in any other region ([...] 15). Overall, about 40% of state parks provide some [...] of swimming facility, about 25% provide boating acc[...] and about 60% allow fishing.

Marinas.—Almost half of the 5,000 marinas and b[...] docks in the country are located in the North; anot[...] 40% are in the South. Thus, most of these facilities [...] located in the eastern United States where the majo[...] of coastlines and large population centers are locat[...]

Swimming pools.—Outdoor swimming pools are [...] important local recreation resource, often developed [...]

Table 7.—Area (in thousands of acres) of selected water-related federal resources by type and region.

Region	Type of Area: Acres of National Rivers, Lakeshores, Seashores & Recreation Areas	Bureau of Reclamation Water acres	Miles of Rivers Managed by BLM	Corps of Engineers Water acres
North	846	0	0	124
South	961	72	0	26
Rocky Mountain	4,539	1,628	3,646	90
Pacific	860	538	1,849	279
Total	7,206	2,238	5,495	519

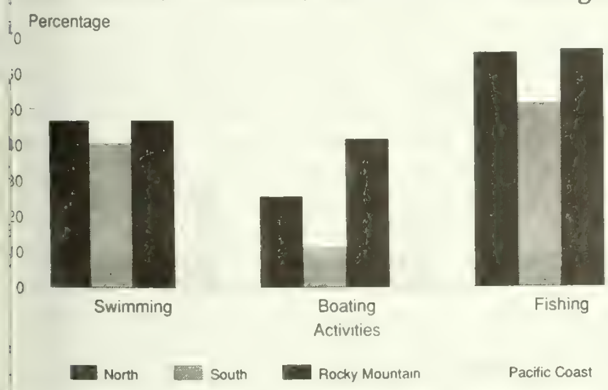
Source: National Outdoor Recreation Supply Information System, USDA Forest Service, Athens, GA (1987).

municipal governments. Nationwide, local governments operate almost 6,500 outdoor pools. Many more are provided as a commercial enterprise. These facilities are heavily concentrated in the East. Over half of the swimming pools open only through memberships are in the North, and about 30% are in the South.

Snow and Ice Resources

Many of the same resources that provide recreational opportunities in summer for activities such as backpacking, hiking, and off-road vehicle driving are also used in winter for activities such as cross-country skiing, snowmobiling, and winter camping. The resource base for these winter activities depends upon the acreage of land and water in climates with suitable snowfall and temperature. All areas available to the public that receive an average snowfall of 16 inches or more a year are considered part of the snow and ice recreation resource base (fig. 16).

More than 625 million acres, about 85% of the entire federal estate, receive adequate snowfall for winter recreation. Well over half of this acreage is located in the West and in Alaska. Only 2% of snow-laden areas within 0.5 mile of a road are located in the North. State agencies manage about 36 million acres of land receiving adequate quantities of snow.



SOURCE: National Outdoor Receation Supply Information System (NORSIS), USDA Forest Service, Athens GA, 1987

Figure 15.—Percentage of state parks providing opportunities for selected water recreational activities.

Trails and Roads for Winter Use

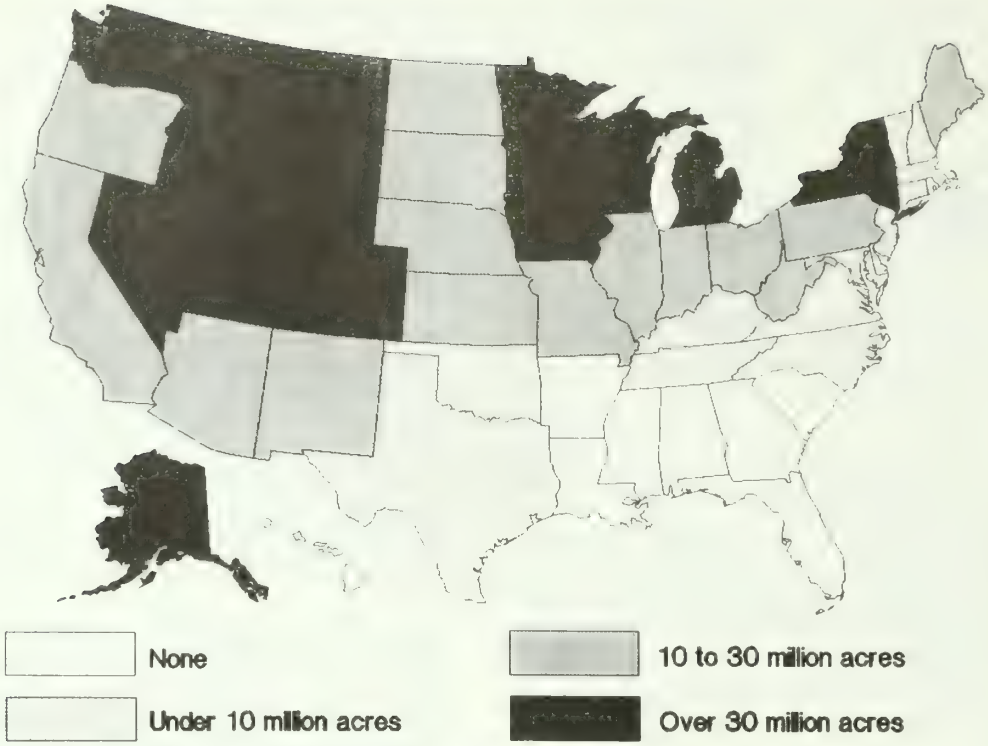
Over 2,000 miles of trails in the National Recreation Trail System (NRTS) may be used for cross-country skiing. Over half of these miles are located in the North. About 1,500 NRTS miles are open to snowmobiles and, again, the majority (60%) are located in the North.

During winter, about 100,000 miles of roads on federal lands receive sufficient snowfall to be used for winter recreational activities. As travel corridors, some of these roads may actually be more important in the winter when trails are impassable or hard to find. Half of these roads are located in the Rocky Mountain Region, and another one-third are in the Pacific Coast states. Almost all (90%) are on lands managed by the Forest Service. Local governments provide winter trails as well. Nationally, over 5,000 miles of local trails are available for winter use.

Cross-Country and Downhill Ski Resorts

Primary commercial opportunities for snow- and ice-based outdoor recreation are downhill and cross-country ski areas. Other forms of outdoor winter activities, such as snowmobiling and sledding, depend only on open areas and enough snow or upon temperatures low enough to freeze pond and lake surfaces for ice skating. The development of ski resorts has been almost exclusively by private investments, although resorts frequently use adjacent public land, most often Forest Service land, for ski runs and lift facilities.

The Nordic ski area directory, published by Ski magazine in 1985, lists over 400 cross-country ski areas. Nearly two-thirds of these areas are in the North. The average number of trail miles maintained per area was highest in the Pacific Coast Region (41) compared to 25 in the North. In recent years, commercially provided cross-country skiing with well groomed trails, lodging, food service, transportation, and other amenities has been



SOURCE: National Outdoor Recreation Supply Information System (NORSIS), USDA Forest Service, Athens GA, 1987.

Figure 16.—Distribution of public and private land acres available for winter recreation by state.

growing rapidly. Ski magazine also listed 382 downhill ski areas. While 58% of the lifts are located in the North, the Rocky Mountain Region boasts greater skier capacity—40% of the national total.

Nationally, about one-third of ski lifts are on national forest lands. In the West, where Forest Service lands are more prevalent, the percentage is higher—83% in the Rocky Mountain Region and 78% in the Pacific Coast Region. Almost 60% of skier lift capacity is at ski areas on national forests, mostly in the West. Only 14% of skier capacity is on national forests in the North.

Conditions and Trends: Changes Occurring to the Outdoor Recreation Resource Base

The above sections have identified the extent of outdoor resources currently available for recreation in terms of acreage, regional distribution, and ownership. But changes are occurring in this country which may substantially affect the size, quality, and availability of the resource base.

Recent Resource Trends

Land.—Recent trends in availability of and access to land recreation environments are somewhat mixed. Despite increased wilderness designations, road developments on public lands have significantly reduced total remote backcountry acreage. Although road developments and purchases have increased the acreage in and access to roaded and partially developed environments on public lands, these increases have been offset by closures of private lands.

The number and capacities of developed land resources such as picnic areas, campgrounds, resorts, nature centers, and golf courses have increased. While some federal sites have been closed or have faced reduced maintenance, local government and private resource investment and management has risen enough to offset federal decreases.

Water.—Remote and wild water resources available for recreation have increased slightly in recent years. Designations of Wild and Scenic Rivers and increases in water quality and guide services (Brown 1985) have all contributed to offset road and other development. The net result has been a small increase in available remote water resources. Some closure of private lands and development on public lands has caused small decreases of opportunities for public recreation on lakes nearer to, but not immediately accessible by, roads. This same development, with added boat ramps, reservoirs, road crossings, and boat rentals, has increased lake and stream resources adjoining roads. This increase has been at rates which closely approximate population growth rates.

The number of intensively-developed water sites has grown rapidly in recent years. Pools, marinas, piers, water amusement parks, and other developments have grown in capacity as well as numbers. As this development is

ccurred, resources available for remote or white water ctivities have decreased. Most of this development for vater recreation opportunities has occurred within the rivate sector.

Snow and ice.—Growth or decline rates for wilderness, ndeveloped and partially developed, and roaded areas n regions where snow and ice are sufficient for winter ports parallel those for undeveloped land resources in eneral. Private land closure has especially limited esource availabilities for snow and ice recreation. Devel-ped winter sports sites, on the other hand, have risen n recent years due both to the development of new areas nd to increases in technology and capacity.

Factors Contributing to Recent Resource Trends of Open Space Losses

Estimates suggest as much as 1.5 million acres of rural and are converted annually to more developed uses USDA FS 1980). Even though this is a tiny portion of he total land base, the impacts on recreation opportuni-es at the local and regional level can be significant and dditive over time. This is because close-to-home open pace, which is the most heavily used and demanded ecreation resource, is most severely threatened by de-elopment. The esthetic integrity of an area can be af-ected when fragmented development occurs, particularly long road corridors once considered a visual scenic esource.

The fastest growth and expansion continues to occur n suburban areas, signifying the demise of the bedroom ommunity and the rise of decentralized urban cores. redicting how this kind of growth has changed and may ontinue to affect general environmental quality and pportunities for outdoor recreation is difficult and spec-ulative. The increased demand for growth management n rapidly developing areas of the country indicates a new wareness and dissatisfaction with the side-effects of apid growth. Around the country, voters are strongly upporting measures to channel and control growth in he interests of preserving local natural resources such s wetlands and undisturbed open space, and other dis-inctive cultural, historic, and esthetic features.

While urbanization erodes the rural private land base, ther factors are also hastening the decline in rural land vailability (Cordell et al. 1985). First is the increased ragmentation of private nonindustrial lands into smaller wnerships, often into tracts under 50 acres (Cordell et l. 1985). Fragmentation makes access contingent upon more land owners and usually signifies changes in wners and reasons for owning the land. Many reasons or owning land are not conducive to public recreation ccess. Second, more landowners are posting their lands o control access (Wright et al. 1989). In 1977, over 29%[2] f the nonindustrial private land base was open to pub-ic recreation. By 1986, that figure had dropped to about 3%. Third, an increasing proportion of rural acres are nder recreational leases for the exclusive use of specif-c groups. Much leasing is monetarily motivated so additional leasing is likely, given the projected increases in the public's desire for recreational access to these lands.

[2] *This figure does not include leased acreage.*

Land Protection

The total amount of federal land managed under specific guidelines which limit kinds of use, either as a park, refuge, or wilderness area, has increased significantly since 1960. Most of the increase resulted from reclassification of public domain lands in Alaska. In addition, many of these same lands in 1980 were added to the NWPS, tripling its acreage.

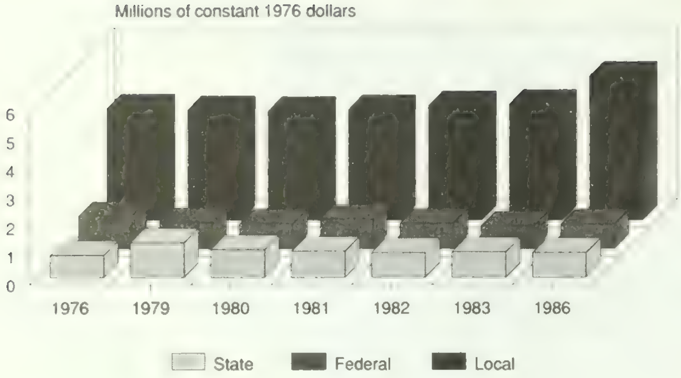
It should be noted that, in total, the federal acreage has decreased since 1980 because many Alaskan public domain lands were turned over to Native American populations or state agencies. Because most multiple-use federal lands may be used for recreational activities, a reduction in the federal acreage generally reduces recreational opportunities. However, it is still true that lands specifically designated for recreation have increased since 1980, despite a total reduction in the size of the federal estate. These special designations do not, however, physically increase the total acreage of resources available for recreation. They merely change the status of existing federal lands.

State protection of lands through outright purchase and special designations has slowed in the 1980's. Additional designations to protected status from existing state parks or state forests are expected to be few (Cook and English 1989). However, much evidence suggests that the natural area preservation movement is young and still growing. The growth of private sector agencies such as The Nature Conservancy are good indicators. For example, in the past few years, The Nature Conservancy has shown growth in total contributions, in contributions over $1,000, in corporate cash and land donations, and in memberships. It seems likely that impetus from the private sector will result in continued growth of this movement.

Facility Degradation and Budgets

Though budget constraints and increased use have emphasized the need for managing recreation, the collective net result has been a general degradation of both facilities and infrastructure. As of the end of fiscal 1986, the Forest Service reported a maintenance backlog in its recreation facilities of $1.7 billion. The NPS reported a $1.9 million shortfall for maintenance and capital improvements in 1988 (General Accounting Office 1988). The General Accounting Office report concluded that "because of advanced, continuing deterioration, some of these assets may be lost permanently." Direct expenditures by the federal government on parks and recreation (fig. 17) has declined 34% (in constant dollars) since 1980 (Bureau of the Census 1987).

State spending for parks and recreation has fluctuated since 1980 (fig. 17). From 1980 to 1984, real-dollar spend-



SOURCE: Bureau of the Census of Government Finances, U.S. Department of Commerce, Government Finances

Figure 17.—Direct government spending for parks and recreation, 1976 to 1986 (constant dollars).

ing declined 13%; from 1984 to 1986, there was a 17.7% gain (both inflation adjusted). The net result is a 2.2% gain since 1982. More significantly, state park budgets declined by 23% from 1980 to 1985, causing increasing concerns about facility deterioration (National Association of State Park Directors 1981, 1986). State forest agencies, however, have roughly doubled their recreation budgets during the same period, resulting in a small net gain when considered across all state agencies. Another important change in states' recreation financing has been the use of fees and charges—up 55% between 1978 and 1984. For example, revenue from entrance and parking fees increased 41% in state park systems from 1980 to 1985, comprising 20% of total revenues in 1985 (National Association of State Parks Directors 1986).

Expenditures for locally managed recreation resources rose 20% (in constant dollars) from 1980 to 1986. However, rising land prices and dwindling open space as the urban fringe expanded have reduced opportunities for reserving more land specifically for recreation.

Local governments have been confronted with three other financial problems. First, the sources traditionally used for capital improvements, the Land and Water Conservation Fund and matching state funds, have been substantially reduced (Mantell et al. 1989). Second, many localities are having more trouble raising money specifically for capital improvements. Third, concern about maintenance and improvement of existing facilities has diverted attention from acquisition of new areas.

Environmental Quality

A polluted environment can reduce the safety and appeal of some recreational pursuits, destroy some outdoor opportunities altogether, reduce the visual quality of landscapes, and threaten the viability of natural habitats upon which many other recreation opportunities depend. Upstream and upwind pollutants, the sources of which are outside park, wilderness, or recreation area boundaries, can compromise much of management's effectiveness and can have detrimental effects on plant and animal health.

Air pollution has affected the quality of outd resources in many ways. Thermal inversions in the So west have caused particulates from some contamin to settle over scenic canyon vistas in various prote areas. Views in national parks, forests, and monum have sometimes been obscured by particulate accu lation in the air. Acid deposition contributes to the back and decline of vulnerable coniferous trees at r tively high altitudes in the Southeast and other part the country. In the northeast and north-central sta some lakes particularly vulnerable to acid deposit have become virtually sterile. The outdoors as a rec tion resource can be seriously affected if smog make unsafe to exercise outside as it does frequently in summer in the Los Angeles basin where much of the S ta Monica Mountains National Recreation Area is loca

In the Everglades in southern Florida, wildlife habi have been significantly reduced as a result of water lution and drainage causing declines in the water ta (Mangun 1983). The enjoyment of such a habitat is nificantly diminished when that which people cam see has disappeared as a result of toxic contaminati

Reduction of phosphate loadings in the Great Lakes greatly reduced algal blooms (the result of eu phication) which closed many beaches in previ decades. However, toxic contaminants still plague Great Lakes and fish populations have suffered (Nati al Research Council, Royal Society of Canada 1985

Other U.S. waters are still so heavily contaminated swimming is considered dangerous. Such places Boston Harbor or the South Branch of the Raritan R in New Jersey, which receive inadequately treated ef ent from industry, septic systems, and nonpoint ur and agricultural sources, are so heavily polluted that t should not be considered part of the recreational reso inventory. Toxic contaminants have also caused mass declines in fisheries, although clean-up efforts on sc rivers in New England have caused a resurgence in populations and the consequent resurgence in recreati al fishing as well.

Shorelines

Development along shorelines contributes to water lution and flooding and directly decreases access recreational resources, especially when a beachfron ringed by private homes and resorts. The Minnes Department of Natural Resources is working to ens that local zoning authorities enforce floodplain dinances so that the quality of resources used for rec ation (which is heavily biased toward water) will rem high (Minnesota Department of Natural Resources 19 In California, more than 23% of the ocean-side state p units experienced beach sand loss, a trend which thr ens the very existence of a very popular recreatio resource (California Department of Parks and Recreat 1984).

CHAPTER II: THE DEMAND FOR OUTDOOR RECREATION AND WILDERNESS

Dramatic social changes have occurred since the Outdoor Recreation Resources Review Commission announced its findings (ORRRC 1962). The U.S. population has grown by 63 million people, although the rate of increase has slowed dramatically from 2.1% to less than 1% per year. The population has shifted south and west with increasing migration to nonmetropolitan cities and communities. Average income continues to increase.

Leisure time increased until the 1970's, but now the amount of time Americans have for leisure appears to be decreasing. Between 1973 and 1984, the average number of leisure hours fell over 31% (Harris 1984). In the 1988 Harris survey, a further decline was observed, resulting in an overall loss of about 37% in 15 years. Harris identified more women in the workforce and longer working hours for factory workers as major reasons. The increased time Americans have devoted to commuting has also depleted leisure. Retired individuals have the greatest amount of leisure while dual income households have the least.

Today, leisure activities are centered closer to home. Outdoor recreation has embraced some new activities and developments which have simplified participation in traditional activities, and changes have occurred in home leisure technology. Contributing to this trend toward "at-home" activity are the aging of the population, rediscovery of the family as the "baby boom generation" bears children, home-video entertainment, and less leisure time.

The post-World War II baby-boom generation is maturing. The average age of Americans is rising and will continue to rise. With this has come a change in activity patterns. For example, even though Americans jogged over 2.5 billion times in 1987, some factors indicate participation in such activities may have peaked (Cordell et al. 1989). We may expect to see many other changes in outdoor recreation activities as a result of an interplay between technology, demographics, socioeconomic conditions, personal preferences, consumer-oriented marketing, and aging. Indicative of such changes in recreational activities, the trade press noted several years ago that some ski areas were working to "gentle" their slopes to accommodate the aging population (Cordell et al. 1989). Similarly, walking for pleasure (and for health) has remained one of the most popular activities (4.3 billion occasions last year) while other forms of exercise seem to be dropping in popularity. Risk and adventure activities have always been popular with young adults. Some managers, however, report that middle-aged individuals are showing increased interest in risk activities (Cordell et al. 1989).

Society is changing from an industrial to a high-technology service and communications society, and government is becoming more decentralized. The change to high technology and service is contributing to significant changes in outdoor recreation apparent over the past 25 years.

Measuring Recreation Demand

Several different expressions are used to represent trends and possible future demand for outdoor recreation and wilderness. Recreation demand is often measured through participation and participation rates, visits, occasions, trips, and activity. **Participation** refers to the act of engaging in recreation and **participation rates** to the number or percentage of people who participate. A **visit** is participation at an identifiable site or area which has distinct entry and exit points such as a state park or national forest. Typically, the number of recreation visits is the statistic maintained in public agency records. A recreation occasion is participation which may or may not involve travel away from home. If the occasion involves travel, then it is a **trip** requiring travel time to and from home to one or more recreation sites or areas, plus the time spent recreating. An **activity**, as used here, is a distinctive kind of recreation participation like camping, bicycling, tennis, or horseback riding.

When trips are discussed in this chapter, they are classified by the activity the participant considered to be the main reason for the trip. **Demand**, then, is the number of activity-specific recreational trips away from home which people would be willing and able to take after they have considered both how much each of those trips will cost in gasoline, fees and other travel expenses, and how much time it will take. Recreation occasions based at home, such as running or bicycling, do not involve travel and typically occur more frequently than trips away from home.

Assessing the demand for wilderness experiences and opportunities is more complex than other outdoor recreation because it involves a number of other uses which may be nonrecreational. Unlike outdoor recreation, the value of scientific, educational, preservational, and other nonrecreational uses transcends the individuals involved as on-site users. The beneficiaries are typically the scientific community, students, future generations, and other more broadly defined groups. For this reason, measures of wilderness uses discussed in this chapter may seem more vague than measures of recreational uses.

Recent Trends in Outdoor Recreation

The rate of increase for some of the more traditional forms of outdoor recreation appears to be leveling off from the rates of the 1950's and 1960's. Some new and some of the more active traditional recreational pursuits have become more popular, and some passive activities less popular. While hours of use in federal recreation areas have remained stable or only increased slightly over the past 10 years, the number of visits has increased. The 2- or 3-week vacations that were the norm just a few years ago are now less common; but, the number of shorter trips, such as day trips or long weekend trips, has increased (Market Opinion Research 1986). Also, more

recreation now takes place close to home, with the median for day trips to federal recreation areas at 25 miles and 130 miles for overnight trips. McLellan and Siehl (1988) summarized the likely future: "In the decade ahead, recreation managers, researchers and policy makers will find need to cope with rapid change; recreation resource concerns increasingly will be people issues and not resource issues alone. People and society change faster and more erratically, than do the natural resources with which we are professionally concerned." In the following sections, some of the major factors of societal change are examined for their effects on outdoor recreation demand.

Factors Influencing Recreation Demand[3]

A number of factors influence trends in demand for outdoor recreation. O'Leary et al. (1988), Hartmann et al. (1988), and O'Leary (1989) examined several major national recreation studies over the past 30 years to identify which factors may shape the future of outdoor recreation participation. The factors identified include: (1) an aging population with earlier retirement; (2) a decline in available leisure; (3) population growth, particularly in the South, the West, and in rural communities (although at slower rates than in the 1950's and 1960's); (4) increasing immigration, probably bringing new patterns of outdoor recreation; (5) a greater percentage of the workforce represented by women, resulting in more dual-income households with increased discretionary income and less family leisure time; (6) a changing family structure including fewer extended families and more single parent families; (7) higher average education levels; (8) greater health-consciousness; (9) baby boomers entering middle age and becoming important consumers; (10) baby boomers delaying marriage and having children; and (11) rapid economic changes. The implications of these factors are substantial. The typical American family may be smaller with more discretionary income, but they have less free time. These families must plan for shorter, but more frequent, vacations and may choose different activities or do activities in a different way than American families of the past. Some of the major factors which will help shape future recreation demand are discussed below.

Population growth rates and geographic distribution.—The U.S. population is growing at a slower rate than in the past. About 100 million people have been added over the past 5 decades, about 2 million people per year. Wharton Econometrics Forecasting Associates estimates that additional growth over the next 5 decades, to the year 2040, will total slightly over 90 million, an annual average increase of only 1.75 million (Cordell et al. 1989). Immigrants will provide a substantial proportion of this expected increase. Geographic redistribution, apart from the well-publicized sunbelt/snowbelt shift, shows important changes in residence patterns with some rapidly growing nonmetropolitan areas. Continued extensive population growth is forecast in coastal states. In the 1970's, the growth rate of nonmetropolitan counties exceeded that of central cities and the suburbs, reversing a long trend. In the 1980's, however, the general trend reversed again with cities and suburbs growing more rapidly. But a number of nonurban counties continued to grow at a rate more than twice that of the nation. These fast growing "exurban" counties are sought by both retirees and the young because of quality-of-life factors such as scenic and recreational amenities and federal lands, particularly parks or wilderness. Also, the estimated 40% of the population living within 50 miles of the ocean in 1984 is projected to double by the twenty-first century.

The post-World War II baby boom continues to have a profound impact on outdoor recreation. Clawson (19[illegible]) calculated that, between 1945 and 1970, there were [illegible] million births above what would have been expected if pre-World War II birth trends continued. Clawson points out that, by 2010, the earliest of the baby boom generation will be 65 years old. Moreover, between 2020 and 2040, the United States will have an unusually large number of older persons. While their activities may change with age, indications are that the baby boom generation will continue their interest in outdoor recreation, with greater participation than their parents. If parental participation affects what children do, the children of that generation also may be expected to participate at high levels.

Participation barriers.—Some Americans simply choose not to participate in outdoor recreation while others face unwanted constraints. Certain periods of the life cycle (such as early child-rearing and old age) reduce recreation opportunities. Other barriers relate to lifestyle including lack of time, lack of money, disabilities, or poor health. A third set of participation barriers relates to recreation opportunities: lack of appropriate facilities within an accessible distance, undesirable recreation places, lack of information about recreation opportunities, poor transportation, or lack of convenience (Hartmann and Walker 1989).

Although virtually all segments of the U.S. population participate in outdoor recreation to some degree, certain barriers seem to affect some segments of society more than others. The 10% of respondents to the 1986 Market Opinion Research poll who said they did not go outdoors for recreation generally were either poor, unmarried, old or physically or mentally disabled. Transportation generally is improving nationwide, but the absence of public transportation may deny outdoor recreation opportunities to many people, particularly the elderly or poor in inner cities (President's Commission on Americans Outdoors 1987).

The 1985–87 Public Area Recreation Visitor Study (PARVS) reported that recreation varies by social group, especially participation rates (Hartmann and Cordell 1989). Overall, people with low or very high income, the

[3]*The material presented in this section is a summary of several unpublished papers prepared for this Assessment. The conclusions of these papers are based on extensive literature reviews and analysis of the Public Area Recreation Visitor Study, which involved interviews with 32,000 users of federal and state recreation areas nationwide. Copies of these papers are on file with the Outdoor Recreation and Wilderness Assessment Group in Athens, Georgia.*

Many Americans face barriers to recreation at some time (such as during early child-rearing or old age). Other barriers relate to lifestyle or lack of recreation opportunities.

aged, disabled, blacks, and less-educated recreationists visiting state and federal lands participate significantly less in many outdoor recreation activities than do the rest of the population. The factors underlying differences in participation are complex, interrelated, and not yet fully understood.

Social-psychological influences.—Current social-psychological issues in outdoor recreation include: (1) meeting the **diversity** of demand that exists and that will continue to grow; (2) designing our recreation opportunities to be fair or **equitable** to various segments of society; (3) resolving **conflicts** that ultimately occur among different user groups; (4) dealing with rapid **changes in society**, values, and technology; and (5) contributing to the long-term **benefits** from recreation (such as greater physical and mental health, better productivity, family stability, cultural pride, and identification) while responding to the pressures of short-term events (Schreyer 1988). These social-psychological issues are having greater influence on recreation participation as society becomes more complex. In addition, choosing strategies to achieve balance among the interests these issues represent is increasingly influencing natural resource policy in the United States. As these issues become more acute, demands for outdoor recreation opportunities will take on a different social context, perhaps well beyond the simple one of providing quality outdoor opportunities.

Socioeconomic make-up.—Recent information from the PARVS shows considerable differences in recreation participation depending on demographic make-up. Age, income, race, disability, and sex seem to be among the more influential factors (Hartmann and Cordell 1989).

Aging of the population is a dominant socioeconomic characteristic. Although that segment of the population which is 65 years and older will continue to fall until about 1995, a result of a lower number of births in the 1920's and the Great Depression of the 1930's, more than half of the population will be over 40 by 2000 (Snyder and Edwards 1984). The amount of participation in most forms of outdoor recreation declines with age. This pattern varies depending on the activity as participation rates for some activities, such as walking for pleasure, even increase with age. Generally, the more physical recreation activities show the sharpest decline with age, but many people participate in outdoor recreation into their 70's and 80's (Hartmann and Cordell 1989).

The patterns of recreation participation change with age. Consider camping, for example. Older individuals commonly seek more developed campgrounds, travel further to reach their destinations, and tend to stay longer at the same site than younger individuals (Hartmann 1988). The strong relationship between age and recreation patterns has important implications for the future. Although the influence of cohort effects have been shown for some activities (English and Cordell 1985), the percentages of the total recreating public will likely follow behaviors similar to the current elderly population. These overall percentages will be influenced by the increasing number of older Americans.

If recreation patterns of older Americans change, those changes are most likely to be increased participation in the more physically demanding activities. The current emphasis on health and physical fitness may impact the choices and opportunities of individuals as they remain healthier and more active for a longer period.

Income is often considered an important factor in outdoor recreation participation. Most visitors to federal and state recreation areas are from middle-income groups. Both low- and high-income groups use such areas less. Travel patterns are somewhat different depending on income. People with higher income travel further and stay longer. Some expensive activities, such as sailing, show a strong relationship to income while others, such as walking for pleasure, show no such pattern. These findings indicate that income can be an important barrier to participation in some activities, but other activities are available to all. This pattern is likely to continue, indicating that the economically disadvantaged will continue to lack certain recreation opportunities in the foreseeable future.

While incomes generally are trending upward, the President's Commission on Americans Outdoors discerned a bipolarity in the income statistics: the middle class, those earning between $15,000 and $30,000 per year, is shrinking. Income distribution projections show polarization toward more high- and low-income families. Households with incomes over $50,000 (in 1980 dollars) are projected to triple by the mid-1990's. Older Americans have become more financially stable, and are an actively sought market in recreation, travel, and tourism. This could cause increased demand for private recreation by those who can afford it and a corresponding need for public recreation by those in lower-income groups.

The population is also becoming more ethnically diverse. Immigration and very high birth rates among minority populations are rapidly changing the composition of American society. The American-Asian population increased 146% between 1970 and 1980; the Hispanic population rose by 56% between 1970 and 1982 (Cordell et al. 1989). During this same period, the black population grew by only 22% and the white population by only 11%.

Differences exist in recreation patterns among these different racial groups. Blacks are usually underrepresented in resource-based, nonurban outdoor activities. Additionally, some activities appear to be more popular with one racial group than another. Although very little research has been conducted on racial differences in outdoor recreation participation, analysis of the PARVS data has shown that camping, day hiking, wildlife observation, motorboating, and most winter activities have higher participation rates among whites than nonwhites. Picnicking typically has higher participation rate among nonwhites. Despite these differences, participation rates were close between racial groups for many activities. Also, trip patterns are different between these groups. Nonwhites tend to visit areas closer to home and have considerably shorter lengths of stay at recreation areas than whites (Hartmann and Overdevest 1990).

Although the era of legal discrimination based on race has passed in this country, significant differences in recreation behavior among the races persist. The reasons for these participation differences among the races are currently unresolved. Cultural norms possibly play a large role in determining participation behaviors. However, intervening factors such as income, education, transportation, and information may also produce differential participation barriers for some racial groups (Hartmann and Overdevest 1990).

Continued efforts to promote racially equal opportunity may act to increase resource-based recreation participation by nonwhites in the long term. However, if recreation differences are primarily cultural, rather than opportunity differences, the changing racial composition of the population and the resultant mixing of cultures may eventually produce a mix of activities desired by the population as a whole.

Participation differences also exist between men and women. In general, men participate more frequently in strenuous activities than women (O'Leary et al. 198[illegible]). Also, the decline in outdoor recreation participation occurs earlier in life for women than for men. For some activities, such as all forms of hunting, men have a higher rate of participation. Participation rates in other activities, such as developed camping, are nearly equal. Some activities, such as walking for pleasure, show a higher participation rate by women. Differences in recreation trip characteristics are minor between men and women, however. The reasons for these differences are a matter of speculation, and how the long-term influence of the "women's movement" will affect participation patterns remains unknown.

Social groups are another important influence on recreation behavior. They include the immediate household, the individuals with whom people recreate, and possibly the social groups with which people associate during nonleisure (Hartmann 1988). The American household is changing. Single-parent families doubled between 1970 and 1984, reaching 6.6 million. Although the divorce rate is expected to stabilize, estimates are that half of all children today will eventually live in a home without a father.

The 1982–83 National Recreation Survey (NRS) examined those individuals over age 60 who were teaching recreation skills to others and found that most were teaching their skills to family or friends (USDI N[illegible] 1986). With an increasingly mobile society and a trend away from extended families living together, the opportunities for passing recreation skills from one generation to another may be reduced, especially the more complex skills such as hunting and fishing. This influence may contribute to a reduction in the number of individuals who know how to do these activities and ultimately lead to a reduction in participation. Also, the composition of the group with whom one participates influences both the choice of activity and the duration of those activities. The presence of the elderly or children in the group was especially important in determining camping style and duration on Forest Service lands (Hartmann 1988). With an aging society, coparticipant group influences may deserve increased attention in the future, especially [illegible]

he presence of older individuals seems to have a strong nfluence on the activities of the entire group.

Disabilities.—The recreation patterns of disabled beople are quite different from other individuals. Disıbled people participate less per capita in all forms of ecreation than other individuals, but many of the disıbled have more leisure. Also, a smaller percentage of he disabled participate in outdoor recreation than the ıondisabled population. Some activities which are more :ommonly participated in by disabled individuals nclude sightseeing, picnicking, walking, driving for bleasure, developed camping, and fishing. Intervening actors, such as advanced age and low income, add to he recreation constraints of many disabled individuals. ome studies have shown that attitudes of recreation area bersonnel, lack of information about recreation opporunities, and fear of the unknown may actually be more ormidable barriers than physical impairments for many lisabled individuals (Hartmann and Walker 1989). As lisabled individuals become more accepted in society nd as technology permits them greater mobility, more lisabled individuals will likely use public recreation reas in the future. Recreation area managers, planners, nd policy makers should expect increased use of these reas by disabled individuals.

Technology.—Technology directly creates new recretion equipment and uses, but a large part of technologcal advancement has come from military and other ıonrecreation sources. From military technology has ome four-wheel drive vehicles, rubber rafts, and the barachute. Much of the available outdoor clothing and amping equipment has also come from military reearch. More recently, space technology has provided he lightweight "space blanket" and many other mateials which have been adapted to outdoor recreation ıses. Other recent technological advancements have been made in television, transportation, medicine, natural sciences, structures, and computers. Rapid technological advancements add an element of uncertainty to long-range recreation planning (Shafer et al. 1988).

Attendance at Public Recreation Areas

Recent estimates developed for this Assessment indicate the relative proportions of outdoor recreation use which occur on sites managed by each of the four major resource owners. These estimates focus on visitation and draw upon several sources, such as the PARVS, the 1982–83 NRS, agency visitation records, and research studies reporting lengths of stay at various recreation sites. They show that federal lands receive an estimated 12% of all outdoor recreation participation, state lands receive about 14%, local recreation opportunities account for 60%, and private lands and enterprises provide for about 14%.

Visitation to federal outdoor recreation areas.—The annual Federal Recreation Fee Report (USDI 1974–1987) describes visitation to federal recreation areas managed by seven federal agencies (Forest Service, Park Service, Bureau of Land Management, Fish and Wildlife Service, Bureau of Reclamation, Tennessee Valley Authority, and Corps of Engineers). The majority of areas managed by these agencies are in forest and rangeland settings; some are predominantly water. Overall, the number of visitor days on these areas increased 4% from 1977 to 1987 (table 8). Although some agencies had slight declines in recreation use (fig. 18), visitor days of use at national forest sites increased by over 16%. Also, while total visitor days during this period were changing erratically, and their total rose only slightly past their previous 1977 level, **number of visits** to some federal land systems increased more rapidly. This difference between total visitor time on sites and number of visits reflects visits of shorter duration.

Table 8.—Thousands of visitor days to federal sites (and index to 1977).

Agency	Year 1977	1980	1984	1987
Forest Service	204,797 (100.0)	234,899 (114.7)	227,554 (111.1)	238,458 (116.4)
Corps of Engineers	162,750 (100.0)	160,529 (99.6)	137,657 (84.6)	148,683 (91.4)
National Park Service	92,029 (100.0)	86,807 (94.3)	103,296 (112.2)	114,753 (124.7)
Bureau of Land Management	60,226 (100.0)	5,692 (9.5)	17,349 (28.8)	43,099 (71.4)
Tennessee Valley Authority	7,038 (100.0)	7,268 (103.3)	6,620 (94.1)	6,508 (92.5)
Bureau of Reclamation	33,607 (100.0)	33,932 (101.0)	23,515 (70.0)	31,783 (94.6)
Fish and Wildlife Service	6,010 (100.0)	1,451 (24.1)	4,791 (79.7)	5,973 (99.4)
Total	566,457 (100.0)	530,578 (93.7)	520,782 (91.9)	589,257 (104.0)

Source: U.S. Department of Interior (1974–1987) Federal Recreation Fee Report.

For visits to national forests, the percentage of all trips that were 2 hours or less in travel time increased from 43% in 1977 to 72% in 1986. Meanwhile, the number of trips of greater than 8 hours travel time dropped sharply from 23% in 1977 to 6% of all trips in 1986 for national forests, and from 41% in 1977 to 9% in 1986 for national parks (table 9). The percentage of repeat visits is increasing for both national forests and national parks (table 9). Length of stay has changed as well, with proportion of visits of 1 day or less increasing, and visits of more than 1 day (24 hours) declining (table 9).

Visitation to state outdoor recreation areas.—In 1979, about 92% of state park users were day visitors while about 8% stayed overnight. In 1980, day users constituted about 87% of visitors; and by 1986, total use was about 90% day use and 10% overnight use. State recreation area visitation has held fairly constant over the past 10 years with about 9 of every 10 visitors making a day visit to state parks. State parks are continuing to serve public needs for primarily day-use recreation (USDI 1974–1987).

Newly available data from the PARVS provides additional information on the trip characteristics and recreation activities of visitors to state recreation areas. These data confirm that most visitors to state recreation areas are day users. Most day visits to state parks are about 3 to 4 hours. The median one-way travel distance for day visitors ranged between 25 and 35 miles, depending on the region of the country. Longer trips in the Rocky Mountain Region produced a higher mean travel distance than in the eastern regions. For overnight visitors, median length of stay is a little over 2 days for state areas while

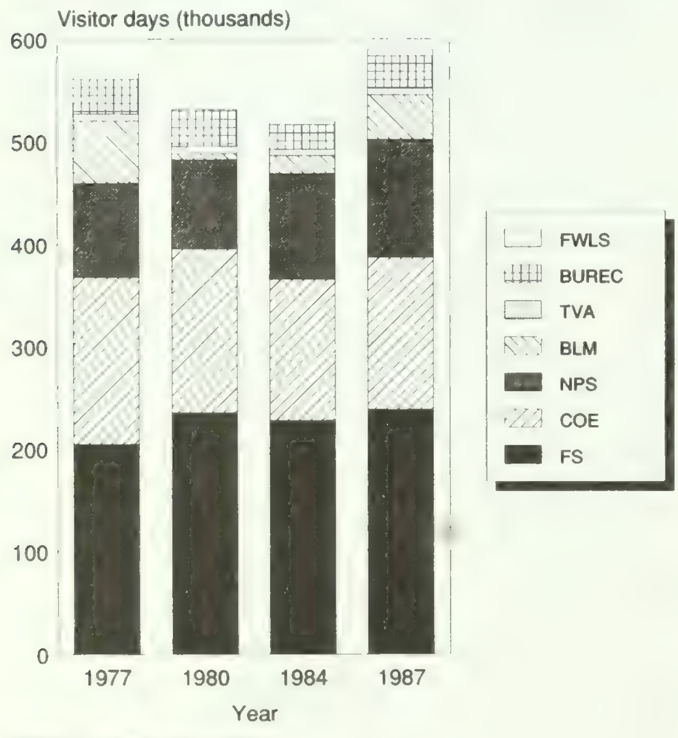


Figure 18.—Recreational visitor days for federal land management agencies, 1977 to 1987.

Table 9.—Comparison of reported length of stay, repeat visits, and one-way travel time for two federal agencies, 1977 and 1986.

	Forest Service		Park Service	
	1977	1986	1977	1986
	percent			
Length of stay				
0–2 hours	6	26	28	[illegible]
2–4 hours	8	22	13	[illegible]
4 hours to 1 day	16	31	19	[illegible]
more than 1 day	70	21	40	[illegible]
Repeat visits				
0	40	23	63	[illegible]
1–2	24	28	16	[illegible]
3–5	14	16	8	[illegible]
more than 5	22	33	13	[illegible]
Travel time (hours)				
< 2	43	72	31	[illegible]
3–4	19	14	13	[illegible]
5–8	16	8	15	[illegible]
> 8	23	6	41	[illegible]

Source: 1977 Federal Estate Visitor Survey; 1985–87 Public Area Re[illegible] ation Visitor Survey.

the mean length of stay is about 3.5 days. Median repor[illegible] travel time for overnight visitors to state recreation ar[illegible] is about 2 hours; median miles traveled to reach th[illegible] areas is 85 miles. Popular recreation activities in st[illegible] parks are similar to those in federal areas. Active spo[illegible] such as swimming and fishing appear to be more pop[illegible] lar at state areas, and sightseeing was more popular [illegible] federal areas. Some regional differences were evid[illegible] (Betz and Cordell 1989).

Visitation to local outdoor recreation areas.—T[illegible] Municipal and County Park and Recreation Stu[illegible] (MACPARS), completed in 1985, estimated that betwe[illegible] 125 and 175 million individuals are served annually [illegible] over 7,000 local park and recreation departme[illegible] (McDonald and Cordell 1988). This represents betwe[illegible] 51% and 72% of the U.S. population.[4] The 1986 Mar[illegible] Opinion Research report found that three out of fo[illegible] American adults visited a local park at least once [illegible] 1985, representing 140 million adults over 18 years [illegible] age. A recent trend toward shorter, closer-to-ho[illegible] vacations may mean that local park demand will increa[illegible] even more. Organized sports, such as baseball, softba[illegible] and football, represent one form of developed outdo[illegible] recreation that involves most American children, eith[illegible] as participants or as spectators. However, surveys ty[illegible] ically do not include children and, thus, fail to cou[illegible] the very large number of youths being served throu[illegible] local recreation programs, including nature cente[illegible] local parks, and developed sports programs.[5]

Demand for local park and recreation opportunities [illegible] difficult to quantify, particularly at the national lev[illegible]

[4]*These figures are calculated as follows: park and recreation dep[illegible] ments nationwide are estimated between 5,000 and 7,000 in numb[illegible] these departments serve an average of 25,000 people each.*

[5]*Municipal and County Park and Recreation Study (McDonald [illegible] Cordell 1988), and weighted to U.S. Census of Governments data by co[illegible] munity size and recreation budget size. For communities of under 25,[illegible] population, unweighted data are used.*

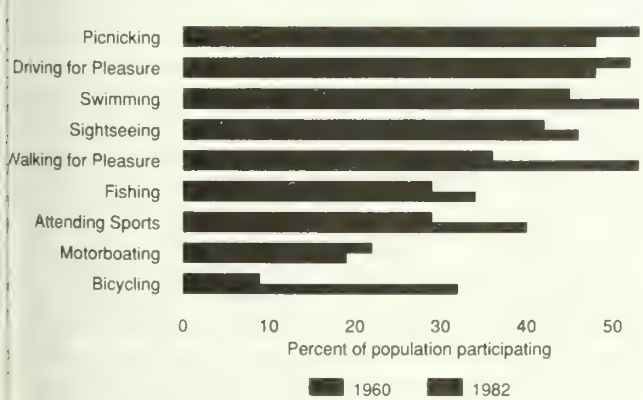
[The variety and scarcity of use reporting schemes, the ıutonomy of local government operations, and lack of ı unified system of service delivery all complicate evaluıtion. At the local level, the growth and continued ›ublic support of local park and recreation operations ıre indications of strong public demand. According to he MACPARS (McDonald and Cordell 1988), operating ›udgets in local departments rose a median of 25% beween 1983 and 1985. While not a direct measure of lemand, this level of local support for park and recreaion departments indicates a desire for their services and demand for close-to-home recreation opportunities, vhich may increase even more in the future.

ʼarticipation in Outdoor Recreation Activities

General trends in recreation participation.—Surveys ›f public participation, both by public agencies and ›rivate organizations, generally point to continued ;rowth in demand for outdoor recreation. While the out:oor recreation surveys of the past 3 decades are not trictly comparable, they do point to some general trends or specific activities and to how participation has grown r declined. For example, a comparison of the 1960 and 982–83 NRS shows an increase in percentage of the ›opulation that participated in six of nine popular outloor activities (fig. 19). Many of these are vigorous ctivities, such as bicycling, walking for pleasure, and wimming.

The A.C. Nielsen Co. surveyed participants in some ypical outdoor recreation pursuits at 3-year intervals rom 1973 to 1982. The survey showed the participation ate for bicycling, fishing, boating, and snow-skiing ncreasing between 1973 and 1982 while the swimming ›articipation rate declined and camping rose and then ell between 1973 and 1979 (Nielsen 1982).

More recently, a survey conducted by Market Opinon Research (1986) showed the relative popularity of nany outdoor activities. This survey found that walkng or driving for pleasure, sightseeing, picnicking, wimming, visiting zoos and fairs, attending outdoor ports events, visiting historic sites, fishing, bicycling,



SOURCE: U.S. Department of the Interior 1986

Figure 19.—National trends in participation in selected activities (people age 12 and older) 1960 and 1982.

Table 10.—Percentages of population participating in outdoor recreation activities in two time periods, 1977 and 1987.

Activity group and activity	Percentage of participants participating at least once annually	
	1977 (households)	1987 (individuals)
	------------ percent	------------
Land-based		
Camping (developed)	30	20
Camping (dispersed '77) (primitive '87)	21	11
Driving off-road vehicle	26	12
Hiking	28	16
Horseback riding	15	10
Nature study/photography	50	13
Picnicking	72	54
Pleasure driving	69	54
Sightseeing	62	51
Water-based		
Canoeing	16	9
Sailing	11	7
Other boating	34	7
Swimming outdoors	61	*
Outdoor pool swimming	*	48
Non-pool swimming	*	35
Water skiing	16	10
Snow/ice-based		
Cross-country skiing	2	4
Downhill skiing	7	7
Ice skating	16	7
Sledding	21	5
Snowmobiling	8	4

NOTE: Sampling and methods were different between the above two cited studies. The 1977 study reported percent of households participating in outdoor recreation by type of activity. The 1985–87 study reported percent participation by individuals. Differerences between percentages reflect survey methods and measurement of household versus individual participation. Higher household percentages reflect high probabilities that at least one person in a household is a participant.

Source: USDA Forest Service's 1979 Resources Planning Act Assessment; 1985–87 Public Area Recreation Visitor Study.

**No data available for these categories.*

and camping topped the list of participation rates among Americans.

Even more recent data on outdoor recreation participation has been developed from PARVS for this Assessment (Cordell et al. 1987). PARVS is the successor to the Federal Estate Visitor Survey which served as a data base for the 1979 RPA Assessment's recreation analysis. Analysis of these two surveys shows the changes in participation rates of selected activities (table 10).

Another measure of participation is **rank order** of the percentage of population participating in activities. This allows comparison between surveys using somewhat different methods. Using this ranking system, Hartmann et al. (1989) found that picnicking was the most popular outdoor recreation activity in all surveys except the most recent. The most dramatic change is seen in bicycling which gained in relative popularity over boating between 1960 and 1982. Swimming and walking for pleasure became more popular than picnicking and driving for pleasure. This corresponds to the observed trend of a more active lifestyle for Americans.

Participation data from the 1960 and 1982 NRS can be accurately compared across only nine activities (fig. 19). Differences in questions and definitions between the two surveys (for example, for camping and boating) complicate or preclude trend analysis. Table 11 provides two measures of current outdoor recreation participation. Additionally, trend information from the 1960 and 1982–83 NRS and a synopsis of the most current information available from PARVS is provided for selected activities discussed below. (Hunting and fishing participation is discussed in the Wildlife and Fish Assessment.)

Driving and walking for pleasure.—Pleasure driving and picnicking have the highest participation rates among outdoor recreational activities. Participation spans all demographic segments and is surpassed only by walking for pleasure among the over-60 age group.

Table 11.—Annual participation in selected outdoor recreation activities.

Activities	Percent of population 12 years old and older participating	Median number of days of participation annually
Land-based activities		
Walking for pleasure	60	35
Driving for pleasure	54	21
Picnicking	54	7
Sightseeing	51	15
Bicycling	36	18
Running/jogging	29	42
Family gatherings	23	6
Visiting nature museums	23	3
Camping in developed campgrounds	20	9
Visiting historic sites	20	4
Attending special events	19	3
Day hiking	16	10
Wildlife observation	14	18
Nature study/photography	13	18
Photography	12	14
Driving vehicles or motorcycles off-road	12	12
Camping in primitive campgrounds	11	8
Horseback riding	10	9
Big game hunting	7	11
Small game hunting	6	13
Backpacking	5	7
Water-based activities		
Swimming in outdoor pools	48	16
Swimming in lakes, streams, ocean	35	13
Warmwater fishing	22	21
Motorboating	21	10
Water skiing	10	8
Canoeing/kayaking	9	6
Saltwater fishing	8	12
Coldwater fishing	7	15
Sailing	7	6
Snow and ice-based activities		
Other winter snow activities	12	7
Downhill skiing	7	9
Ice skating	7	5
Sledding	5	5
Snowmobiling	4	9
Cross-country skiing	4	6

Source: 1985–87 Public Area Recreation Visitor Study.

The PARVS found high participation rates in walking for pleasure among all ages, both genders, and nearly all income groups. The median participation per person is 35 days annually.

Day hiking.—Hiking grew significantly in popularity between 1960 and 1982, with 14% of the NRS respondents participating in 1982. The NRS indicated that both men and women enjoyed the activity and that participation remains high up to about age 60, then it drops sharply. Participation in hiking increases with education and income. Current data from PARVS indicates that 10 days annually is the median participation per person in the United States and that 16% of the U.S. population over 11 years old participated at least once annually. About 20% of participants go hiking more than 15 days annually. Persons over age 40 have a lower participation rate, but no gender differences are apparent.

Camping.—Camping, including backpacking, almost doubled in rate of participation between 1960 and 1982. Camping has traditionally been among the most popular outdoor activities among both sexes and among people of varying ages, education levels, and incomes. Data from PARVS showed clear differences among participants depending on camping style. Backpackers are generally fairly small family or friendship groups who are young, highly educated professionals, with a high percentage of males and very few accompanying young children or elderly. Groups camping in primitive or developed campgrounds represent a broader spectrum, having nearly equal gender ratios, being middle income, and often containing both elderly and young children. These groups are most often families (Hartmann 19[illegible]). Some 20% of the recreating public camped at developed sites, with a median of 9 days annually. Over 11% of the recreating public camped in primitive campgrounds, with a median of 8 days annually. Backpacking involves about 5% of the recreating public, with a median of 7 days annually.

Off-road vehicle driving.—Off-road vehicle driving, including motorcycles, four-wheel drive all-terrain vehicles, and beach buggies, was not a prominent activity in 1960. The 11% participation reported in 1982 represents significant growth since 1960. PARVS shows 12% of recreationists currently participate, which represents over 20 million people. These participants are generally young (60% under age 30) and are 64% male. Median days of participation is 12. (Note: In this assessment, snowmobiling is not included in the more general category of off-road vehicles but is discussed separately.)

Horseback riding.—About 9% of NRS respondents said they engaged in horseback riding, a rate that has been fairly stable since the 1960's. PARVS shows an interesting distribution of the frequency of participation indicating two main groups: a majority who probably rent horses for a few days a year, and an avid minority who likely own their own horses and ride as often as possible. Horseback riding is somewhat more popular among women than men, and the largest group of participants is aged 15–19.

Different types of recreation activities attract different people. People using developed campgrounds represent a broad spectrum of users.

Bicycling.—Bicycling has gained dramatically in popularity since 1960, more than tripling its population participation rate. Based on the 1982 NRS, 37% of young adults (aged 25–39) said they bicycled, and 22% of the middle aged (40–59 years) said they did. An estimated 78 million Americans bicycle, more than half of whom are over 18 years of age and more than half of whom are women (Moran et al. 1986). Physical fitness and enjoyment of nature were given as major reasons for pursuing the sport.

Technology has broadened participation in bicycling. In addition to the traditional child's bicycle, touring, racing, mountain, and adult three-wheeled bicycles are now available. Each offers a different recreational experience to a different clientele. In 1985, more than 100,000 young people participated in dirt bike motocross racing; 8,000 persons participated in 110 sanctioned mountain bike events; and 600,000 Americans took a bicycle vacation or extended tour (Moran et al. 1986). PARVS indicated participation by 76 million Americans over age 11 each year, confirming the NRS figure and revealing that 36.4% of the population participated at least once annually. The data also showed that the median frequency for bicycling is 18 days, but 20% of participants over age 12 participate 60 days or more per year. About 115 million biking trips away from home are made each year by the American public.

Swimming outdoors.—Outdoor swimming was already extremely popular in 1960, but participation increased from 45% to 51% between the 1960 and 1982 NRS surveys. In the 1982 survey, a somewhat larger proportion of respondents said they swam in outdoor pools rather than in natural environments. Currently, swimming is still very popular with 48% of the PARVS respondents participating in pool swimming at least once annually. Median number of annual participation days is 16, with 20% of participants swimming on 50 different days each year. Women make up about 55% of participants in outdoor swimming, which is popular nationwide and with all age, education, and income groups.

Boating.—The 1982–83 NRS reported the participation rate for the general category of "boating" as 28%. That study found participation tends to be greater among higher income and education groups. Little difference in participation rates exist between men and women, and participation continues through middle age. Of all boating activities, canoeing or kayaking had the largest participation growth, from 2% in the 1960 survey to 8% in 1982. More information on specific types of boating is presented below from the PARVS data set.

Canoeing/kayaking.—The current participation rate from the PARVS study for this activity shows that about 9% of the recreating public participates. These individuals participate a median of 6 days per year. They are generally young, 60% are under age 35. Men make up 54% of participants, and income of participants roughly follows that of the U.S. population.

Sailing.—About 7% of the recreating public participates in sailing, for a median of 6 days each year. These participants are generally young (under 35) and slightly more women than men participate. Sailing can be an expensive sport; thus, it is not surprising that the proportion of the public that sails rises dramatically with income. Over 25% of participants have family incomes over $50,000.

Motorboating.—Twenty-one percent of the recreating public uses motor boats at least once a year, with a median participation of 10 days. Motorboating is less age-related than most other outdoor recreation activities, and men make up about 55% of participants. Graefe (1986) reported that expenditures for boating have grown

from $7.5 billion in 1979 to $12 billion in 1984. Also, small boats account for the majority of recreational motorboats; 62% are 16 feet or less.

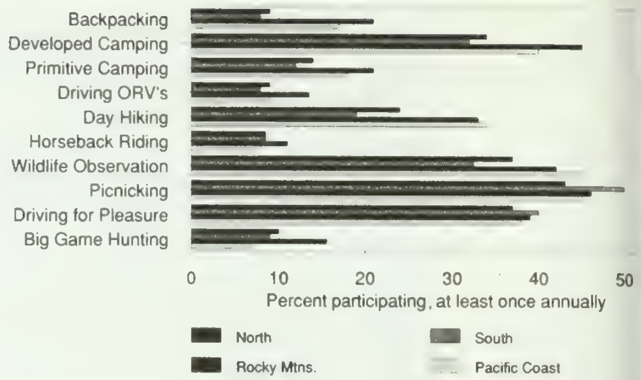
Cross-country skiing.—Immigrants from northern Europe brought cross-country skiing to America. As a recreation, cross-country skiing declined to insignificance by the 1960's and was not even considered in the 1960 ORRRC survey. Also known as Nordic skiing or ski touring, cross-country skiing's rise to a 3% participation rate in 1982–83 (4% to 5% outside the South) grew from a base of almost zero. The NRS found the demographic pattern of skiers to be similar to that of downhill skiers, except that it is markedly less popular among urban people and its popularity continues into middle age. PARVS reported that the median number of participation days was 6, and that individuals aged 25–35 dominated the activity although individuals of all ages participated. About 4% of the U.S. population over age 11 participates.

Downhill skiing.—Participation in downhill skiing is typically an activity for young, affluent adults. At least once annually, 7% of recreating Americans participate, with a median of 9 days. Of these participants, 60% are aged 15–30, and men comprise about 55% of participants. About 50% of participants have family incomes of at least $35,000, and over 25% have incomes of $50,000 and above.

Snowmobiling.—Motorized, over-snow vehicles have been used for several decades where heavy snow cover persists for long periods. Snowmobiling as a recreational activity was just beginning to become popular in the United States in the 1960's. The 3% participation rate recorded in the 1982 NRS survey represents much growth since 1960. The 1982–83 NRS found that the demographic traits of snowmobilers are similar to cross-country skiers, except that snowmobiling attracts a smaller percentage of those individuals in the higher education and income categories. Currently, an estimated 4% of people over age 12 participate about 9 days per year.

Regional Variation in Outdoor Recreation Participation

Data from the 1985–87 PARVS show some striking regional differences in the kinds of outdoor activities people pursue (fig. 20). As one might expect, the data largely reflect differences in opportunities among the regions. For example, backpacking is more prevalent in the Pacific and Rocky Mountain Regions than in the South and North, probably because the former have more public land. The South and North surpass the Pacific and Rocky Mountains in warm freshwater fishing while the situation is reversed for cold freshwater fishing. Where opportunities are similar, no extreme differences in participation are apparent among regions. Differences in travel characteristics do exist among regions. Individuals from the Pacific Coast travel further on recreation trips than recreationists from other regions—nearly twice as far as recreationists from the South. Individuals from the Rocky Mountain Region stay longer on site than



Source: 1985-1987 Public Area Recreation Visitor Study

Figure 20.—Regional differences in annual recreation participat by origin of respondent.

those from other regions, particularly longer than in t South.

Recreation Trends Which May Carry into the Futu

More than 100 recreation researchers attended t 1985 National Outdoor Recreation Trends symposiu They examined persistent trends for their possible i plications for future outdoor recreation in the Unit States. Below is a synthesis of major points relating t participation and demand (McLellan 1986).

The role of outdoor recreation in American life co tinues to expand. While the mix of activities has be changing, participation in traditional activities has n increased as sharply as it did in the 1960's and 1970' though it should continue to grow. Increases in parti pation have been particularly noticeable in physica demanding activities, such as bicycling, canoeir kayaking, developed camping, downhill skiing, cro country skiing, water skiing, and snowmobiling. The activities have had broad appeal for the baby boo generation because many are available to a broad ec nomic segment of the population and could be fou relatively close to home.

Participation has leveled off in boating, horseba riding, fishing, swimming, golf, tennis, picnickir driving for pleasure, and driving motorcycles and oth motor vehicles off-road. Many of these activities peak in the 1970's and early 1980's and were not expect to grow in the next 15 to 20 years. Decreased particip tion in hunting was predicted. Many of these predictio have, thus far, held true, but others were short-te anomalies.

Outdoor risk and adventure recreation, encompassi such activities as white water sports, rock climbing, i climbing, and hang gliding, were expected to contin growing in popularity. This demand growth was e pected to come from a more urbanized, mobile, a affluent population. The demand could be dampened l increased transportation costs and competition for ava able resources (Ewert 1989).

As it had in the past, technology was influencing re reation as equipment development made new activiti

ɔossible. Researchers conjectured the possibility of snow urfing, jet-pack backcountry camping, jet snow skis, nd personal all-terrain hovercraft. Technology was also xpected to improve safety and communications, making more people feel more secure in outdoor activity Shafer 1989).

Jse of Public Recreation Areas by Foreign Visitors

The growth in tourism from foreign visitors has been ramatic. Between 1960 and 1981, foreign visitors to the Jnited States increased from 602,000 to more than 8 milion (Stronge 1983). Although Americans traveling overeas still outnumber foreign visitors to this country, the ap has narrowed significantly. International travel is major export industry. International tourism services ; the third largest export industry in the United States Little 1980). Wynegar (1986) estimated that more than 3 million international visitors would travel to the Jnited States in 1987, and total domestic earnings would mount to nearly $17 billion. Overall, international ourism accounts for about 5% of total U.S. tourism inustry earnings (Little 1980). It is estimated that more han 5% of direct tourism jobs are attributable to international visitors. Overall, tourism ranks among the top three employers in 40 states.

Outdoor recreation sites and opportunities are an important attractant to foreign tourists, although information on total numbers of foreign visitors who participate in outdoor recreation on forest and range lands is sparse. It is believed, however, to be substantial (Manning 1980). Internationally known areas such as Yellowstone, Yosemite, and Grand Canyon National Parks attract thousands of foreign visitors each year.

Data collected through the PARVS and the In-Flight Survey, conducted by the U.S. Travel and Tourism Administration, provide a rough picture of the characteristics and outdoor recreation patterns of foreign visitors to the United States (Andereck et al. 1989). Although foreign visitors were a small portion of the total sample, more than 40% of the foreign respondents contacted in the PARVS were from Canada. Foreign visitors differed in some respects from domestic visitors, according to the PARVS data (table 12). Foreign visitors tended to be older, from professional or technical occupations, and to have more years of education than domestic visitors to U.S. public recreation lands. About one-third of foreign visitors were on a repeat visit to the recreation area where they were contacted, and scenic beauty was a

Table 12.—Comparison of foreign and domestic visitors to public lands in the United States, 1986.

	Foreign	Domestic		Foreign	Domestic
	----- *percent* -----			----- *percent* -----	
Social group			**Employment status**		
Family	70.9	61.3	Employed full time	52.3	43.4
Group of friends	18.1	18.0	Student	11.9	13.8
Single individual	8.0	10.7	Self-employed	9.6	6.7
Family/friends	—	8.0	Retired	9.3	10.6
Organized group	2.2	1.9	Homemaker	7.6	9.0
			Other[1]	9.3	12.6
			Income		
			Less than $5,000	5.1	4.4
			$5,000-$10,000	5.1	5.4
			10,000-15,000	6.5	9.2
Education			15,000-20,000	11.6	10.1
17 years or more	31.3	11.5	20,000-25,000	10.1	12.4
16 years (college)	30.2	17.4	25,000-30,000	10.1	11.5
13 to 15 years	16.3	23.2	30,000-35,000	9.8	11.5
12th grade	14.2	29.7	35,000-50,000	24.2	21.1
9th to 11th grade	4.7	13.9	50,000 or more	17.4	14.4
8th grade or less	3.4	4.4			
Age			**Usual occupation**		
Less/25 years	20.3	28.1	Professional, tech.		
25–39 years	37.3	44.2	or kindred work.	46.2	30.3
40–59 years	31.2	19.3	Student	10.8	13.5
60+ years	9.2	8.5	Manager or administrator	8.7	9.4
			Craft and kindred	7.3	5.8
Race			Homemaker	7.3	9.8
White	90.4	87.9	Armed forces	3.5	1.4
Hispanic origin	3.3	3.9	Service workers	3.1	4.7
Other[2]	6.3	8.2	Other[3]	12.6	21.4

[1] *Includes "not employed" and "employed part-time" categories.*

[2] *Includes Asian or Pacific Islanders, American Indian or Alaskan Native, and Black- not Hispanic origin.*

[3] *Includes clerical, sales, unemployed, laborer, except farm, operative and kindred workers, and transport equipment workers.*

Source: 1985–1987 Public Area Recreation Visitor Study.

principal reason for their visit. Generally, foreign visitors participated more as sightseers, walkers, pleasure drivers, and developed campers than did domestic visitors (Andereck et al. 1989).

It is likely that the demand for outdoor recreation by international visitors will increase in the future. The U.S. Travel and Tourism Administration projected a 12% growth of international travel to the United States in 1987 and a 2% increase in 1988 (Wynegar 1986).

Wilderness

The 88.8 million acres in the National Wilderness Preservation System in 1988 represents a valuable and irreplaceable resource to be carefully preserved for the future. The original Wilderness Act of 1964 specifically authorized the uses of wilderness: "Wilderness areas shall be devoted to the public purposes of recreational, scenic, scientific, educational, conservation, and historical use" (78 Stat. 894). A number of these uses are further endorsed in subsequent acts, including the 1974 Forest and Range Land Renewable Resources Planning Act, the National Forest Management Act of 1976, and the Federal Land Policy Management Act of 1976. The manuals of the Forest Service, Park Service, Fish and Wildlife Service, and Bureau of Land Management accordingly acknowledge and support a variety of recreational and nonrecreational wilderness uses.

While the Wilderness Act emphasizes the protection of pristine areas, it also recognizes recreational values of benefit to contemporary Americans. Wilderness areas provide "outstanding opportunities for solitude for primitive and unconfined type of recreation." Over the 25 years since the Wilderness Act became law, millic of Americans have visited designated wilderness ar for recreation, solitude, and nature appreciation. B recreational use is only one use of wilderness. Oth nonrecreational uses, such as education, science, habi preservation, and ecosystem preservation, are growi in importance and recognition. Recreational and n recreational uses can, in fact, conflict. Wilderness i plies an absence of man's permanent influence and, i some cases, it seems, of recreation itself. Wildern resources frequently are so fragile that even normally l impact kinds of recreational use may detract from a in sufficient quantities, seriously damage wildern sites (Kelly 1989). The same may also be said for ma nonrecreational uses if these uses involve disturban by man, his machinery, or his chemicals.

Trends in Recreational Use of Wilderness

Following World War II, recreational use of wild ness flourished. However, visitation reports indicate t the rate of increase in wilderness recreation visits slow in the late 1970's and early 1980's (table 13) to the p that it had leveled off and even showed decline in so areas (Lucas and Stankey 1989). Total recreational in wilderness was estimated at 14 to 15 million vis days in 1986 (Roggenbuck and Watson 1989). Rec tional use of national forest wilderness areas grew sev fold between 1946 and 1964 at an annual rate of 11. (Lucas and Stankey 1989). Since passage of the 1 Wilderness Act and the substantial increase in wil ness acreage in the National Forest System (now 32 r lion acres), use has increased by 150%, averaging 4.

The 1964 Wilderness Act preserved these areas for "recreation, scenic, scientific, educational, conservation, and historical use." The 88.8 million acres currently in the National Wilderness Preservation System are a valuable and irreplaceable resource.

Table 13.—Trends in recreational use of National Park and National Forest wilderness and backcountry, 1971–1986.

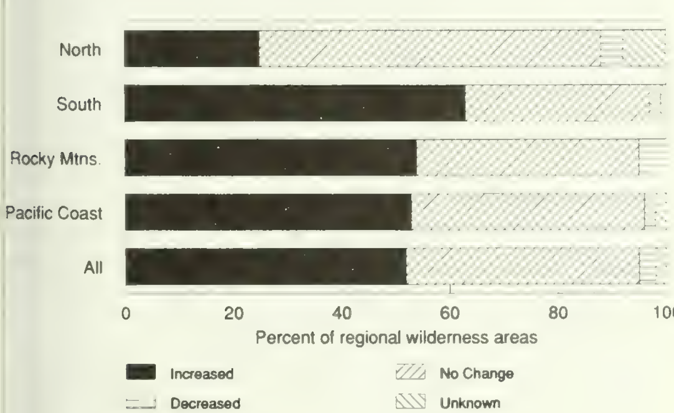
Year	National parks: 17 major wilderness areas (designated in 1964)	National parks: All parks primitive areas	National forests: All wilderness & primitive areas	National forests: Original wilderness & parks
	— thousand overnight stays —		— thousand person-days —	
1971	712	1,096	6,703	6,703
1972	857	1,495	6,459	6,459
1973	910	1,954	6,682	6,665
1974	1,027	2,172	6,743	6,723
1975	1,115	2,346	7,802	7,297
1976	1,231	2,609	7,106	6,790
1977	1,098	2,570	8,008	7,755
1978	904	2,590	8,620	8,291
1979	902	2,397	9,605	8,652
1980	996	2,395	9,268	8,177
1981	968	2,330	11,417	7,984
1982	881	2,424	11,158	7,888
1983	865	2,580	9,909	7,204
1984	833	1,979	10,209	7,534
1985	770	1,680	12,734	7,412
1986	758	1,645	12,015	7,093

Source: Lucas, Robert C., and Stankey, George H. (1989).

per year. Between 1981 and 1986, however, recreational use of wilderness increased 5%, or less than 1% per year. During the early 1980's, year-to-year changes were recorded as downward more often than upward. Still, a recent nationwide telephone survey indicated that managers in more than 50% of wilderness areas believed that recreational use increased somewhat between the years 1986 and 1988 (Reed et al. 1989). This same survey also indicated that less than 5% of wilderness areas had perceived any decreases in recreational use (fig. 21). These more recent data indicate that wilderness recreational use may have turned upward again, a trend consistent with overall public land recreational use.

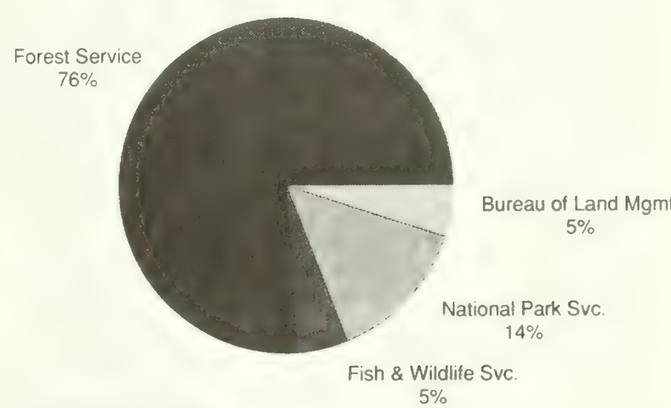
In absolute terms, the growth in national forest wilderness use has exceeded that of many other kinds of recreation taking place in the National Forest System. As a percentage of national forest recreation use and of national forest developed campground use, wilderness use has grown steadily, except in 1986, and now accounts for 5% of total National Forest System recreational use. From data collected through the nationwide telephone survey of managers, it may be estimated (fig. 22) that recreational use in national forest wilderness accounts for more than three-fourths of the National Wilderness Preservation System total (Reed et al. 1989, Roggenbuck and Watson 1989).

Backcountry use in national parks more than doubled between 1971 and 1976, from 1.1 million overnight stays to a peak of 2.6 million in 1976. Since 1976, reported backcountry use has been declining. From 1976 to 1986, national park backcountry use declined 37%, although the number of units which began to report backcountry use increased 20%. Fewer visits were recorded in national park backcountry in 1986 than in 1973. However,



SOURCE: Reed et al. 1988.

Figure 21.—Wilderness managers' perceptions of recreational use trends from 1986 to 1988 by region, all.



SOURCE: Reed et al. 1988.

Figure 22.—Estimated distribution of total recreational use in National Wilderness Preservation System.

the survey of wilderness managers indicated either stable or growing wilderness use between 1986 and 1988, indicating a possible recurring upturn.

The reasons for reported declines in wilderness and backcountry use in the early 1980's are unclear. Changes in population distribution around the United States during this period bear little resemblance to changes in wilderness use patterns. In addition, increasing regulations and a possible image change may have discouraged wilderness use. Regulations to limit use have been imposed in some wilderness areas, although no evidence directly links regulation to declining use. Other possible reasons for this shift in use include an aging population, changing leisure interests (Lucas and Stankey 1989), and a shift in attitudes of the American public from the environmentalism of the 1960's and 1970's to the consumerism of the 1980's (Roggenbuck and Watson 1989). As both of these sources state, perhaps the "yuppie" lifestyle supports the **concept** of wilderness but not its actual on-site use. On the other hand, the image of wilderness camping may be changing. The possibility of being ticketed by a backcountry ranger for illegal camping or for having a campfire, or the fear of contracting giardiasis from contaminated water, may be contributing factors discouraging recreational use of wilderness in the early 1980's. It should be noted that these possible reasons have been suggested by wilderness experts but, as yet, have not been tested or substantiated by research.

Serious shortcomings in how agencies count and estimate wilderness visits complicate analysis. For example, the National Park Service does not count day use in national park backcountry areas. And, because it is difficult to measure day use in national forest wilderness, such counts may be under- or overreported for these areas.

While surveys of wilderness use have been sporadic during the 1970's and 1980's, some trends are apparent. Usage distribution has been very uneven through time, among areas, and even within individual areas. Weekend peaking of wilderness use can be severe, especially in a few of the more popular western wilderness areas which are close to population centers.

Summer is the season of greatest use for most wilderness areas, but the ratio of summer to off-season use varies substantially by area. Some areas have usage peaks of short duration centering on the fall hunting season. In some areas of the East, October is a high-use month because of autumn color. Spring is a high-use time in a few low-elevation areas in the Southwest and in southern California. While winter typically is a very low use period, participation during the winter months seems to be increasing.

A few of the most popular areas typically account for one-third or more of wilderness visitation. Evidence suggests that most wilderness recreation users come from the state or region of the state closest to a wilderness area (Roggenbuck and Watson 1989). Those wilderness areas near major population centers in the southern Appalachians, New England, Minnesota, and California typically are the most intensively used, but location does not explain all the variation. Some swampy wilderness areas in the Southeast are very lightly used, and several of the recently established eastern areas have few visitors despite proximity to population centers. Lack of special attractions, sparsity of trails or travel routes, heavy biting-insect populations in warm weather, and lack of public awareness that these areas exist probably account for the low use. Although wilderness use appears to be spread unevenly across seasons, among areas, and within individual areas, limited evidence indicates an overall trend toward a more even distribution of use within areas and, perhaps, less weekend peaking.

Though recreation is growing more slowly in some national forest wilderness areas and despite the reported decline in national park backcountry use, wilderness recreation will continue as an important pastime, particularly in national forests. National park backcountry areas still account for about 7% of all national park overnight visits. Wilderness use accounts for 5% of national forest recreation use. Moreover, use trends do not reflect the only importance of wilderness.

Nonrecreational Use of Wilderness Areas

Wilderness recreation is only one way that wilderness resources are used and valued. Other values, such as maintenance of species diversity, protection of threatened and endangered species, protection of watersheds, scientific research, and social values, are attributable to wilderness. Sometimes such nonconforming uses as mining and grazing occur in wilderness. Some of these nonrecreational uses are not necessarily exclusive to wilderness settings. Also, some benefits may overlap with those previously attributed to recreational use. Congress does not designate wilderness only for recreation, but as a total resource which includes several nonrecreational uses (Reed 1988). Some recent wilderness legislation suggests the beginning of a trend toward more specific acknowledgment of nonrecreational values. Wilderness user research supports the conclusion that greater consideration should be given to off-site and nonrecreational uses (Roggenbuck and Watson 1989).

Nonrecreational uses of wilderness are widespread throughout the National Wilderness Preservation System. Recent trends, 1986 through 1988, show increases in nonrecreation uses in some wilderness areas (Reed et al. 1989). For example, in 1988, 75% of wilderness areas had identified prehistoric or historic cultural sites. One-half were home to one or more federally- or state-listed threatened or endangered plant or animal species. One-third were used for scientific research, environmental education, or livestock grazing. One-sixth had known spiritual sites, human development programs, subsistence resources, or water storage reservoirs. Because little detailed research has been conducted on the extent of these nonrecreational uses of wilderness, the general public has not always been aware of their value. Many of the benefits of wilderness are not as easily measured or valued as those of timber, water, forage, mining, or even recreation. As a result, many important and valuable

ible aspects of wilderness typically have not been included in the forest planning process. Interest in non-recreational uses and values of wilderness is increasing, and improved methods to measure and describe these uses will have to be developed (Reed 1988, Reed et al. 1989).

Preservation.—Wilderness preserves life-sustaining systems at several different scales. The preservation of natural diversity is essential to our quality of life and vital to our future national and global survival. The passive physical preservation of functional ecosystems in wilderness is an important supplement to active manipulative management of the environment. Ecosystems include not only plant and animal species, but also elements of their habitats including air, soil, water, and microclimate plus physical processes such as fire.

During the Fourth World Wilderness Congress in 1987, 62 nations voted unanimously for preservation of representative samples of all major ecosystems of the world to ensure the preservation of the full range of wilderness and biological diversity. In this country, we are over half way toward that goal. Of the 261 basic ecosystems in the United States, 157 are now represented in the NWPS (Davis 1989). Eighty major ecosystems are not yet represented in any preservation-oriented system (e.g., NWPS, national forest, state wilderness). It is anticipated that most, but not all, of the forest and desert ecosystems in the United States will be represented in the NWPS by 2000. However, additional emphasis is needed on protection of the fertile native grassland ecosystems since most of these lands are in private ownership and lack the scenic splendor that spurs the citizenry to seek wilderness designations (Davis 1989).

Closely related to the preservation of ecosystem diversity is the use of wilderness for preserving genetic diversity, or variation of life forms at or below the species level (Schonewald-Cox and Stohlgren 1989). While some plant and animal species will naturally become extinct, wilderness is important in reducing the extinctions which may result from human actions. Known threatened and endangered species have been reported in 57% of NWPS areas (Reed et al. 1989). About 20% of all wilderness areas contain both plant and animal species that are threatened. Well known threatened and endangered vertebrate wildlife species found in wilderness include the bald eagle, grizzly bear, and the nearly extinct California condor.

While wilderness does not necessarily offer unique opportunities to preserve important historic and prehistoric cultural sites, it may possess sites of unique cultural and environmental interest (Neumann and Reinburg 1989). Prehistoric sites in wilderness, in particular, are valuable preserved records of our natural and cultural histories. Understanding how cultures have dealt with past environmental conditions may teach us much about how we can manage land and water resources, particularly wilderness, with minimal impact. These sites may also yield valuable data on natural changes in species diversity and distribution, plus extent and frequency of natural events such as fire, flooding, and climate change. The number of historic and prehistoric sites within the NWPS is not well known. The exact number and locations of sites are often legally or culturally protected information, but they may number in the tens of thousands nationwide (Neumann and Reinburg 1989). A recent survey of wilderness managers reported that 42% of all wilderness areas had sites of both historic or prehistoric interest (Reed et al. 1989).

External benefits.—Wilderness also protects or enhances resources beyond wilderness boundaries, especially watersheds, air, scenery, and wildlife. Wilderness watersheds may produce valuable water and may also reduce water pollution and flooding outside of wilderness. Because wilderness watersheds remain intact and mostly undisturbed, erosion is minimized and normal runoff does not contribute to accelerated siltation of streams and rivers (Satterlund 1972). As a result, water remains clean, valuable downstream fish spawning areas may be preserved, the lifespan of downstream water storage and distribution facilities may be extended, and the severity of floods downstream is typically reduced.

The quality of wilderness air is not only a benefit to wilderness users but also to users of surrounding areas. As visual mediums and backgrounds, wilderness air may protect the scenic integrity of significant adjacent public lands such as national parks (Yuhnke 1983).

Wilderness areas may also provide temporary or seasonal cover and habitats for migratory wildlife species which only occupy the wilderness for a relatively short but critical time (Schoenfeld and Hendee 1978).

Therapy.—Organized programs for the therapeutic rehabilitation of individuals with various psychological, social, and physiological disorders can be facilitated in wilderness. Such therapeutic programs benefit both individuals and society in general in several ways.

Therapeutic programs for exceptional children and adults (the chronic mentally ill and disturbed children and adolescents) include fostering normal behavior patterns, emotions, social interaction, initiative, perceptual and motor skills, stamina, and group and individual decision making (Levitt 1988).

Although conclusive research is insufficient, the quality of life for all citizens may be enhanced to some degree by such wilderness programs. In addition to the stated benefits, wilderness therapeutic programs may also provide social benefits such as shorter institutionalization time and reduced public expenditures for treatment. Once rehabilitated, many participants may actually add to the economy through their employment, purchasing power, and ability to pay taxes. In 1987, 12% of all wilderness areas nationwide were used as a setting for some type of "therapeutic program" (Reed et al. 1989). However, in some wilderness areas such use is discouraged because it is not considered to be wilderness-dependent.

Human development.—By nature, wilderness provides few, if any, guarantees for the physical comfort, ease, or safety of users. The wilderness setting, therefore, inherently challenges its users. The resulting experiences may serve to enhance a user's self-concept. Williams et al. (1989) described three separate components of the benefits to individual self-concept enhancement associated with wilderness use: personal identity,

national identity, and identification with nature. A number of private human development programs are conducted in wilderness. They include Outward Bound, Vision Quest, and the National Outdoor Leadership School (NOLS). Some type of sponsored human development program occurred in 17% of all wilderness areas nationwide in 1987 (Reed et al. 1989). Again, some wilderness managers do not consider such human development programs to be appropriate uses of wilderness since they are not wilderness-dependent.

Subsistence.—Wilderness often serves as a source of physical subsistence for rural and native Americans (Muth and Glass 1989). Subsistence is the customary use of renewable natural resources by rural subpopulations dependent upon fish, wildlife, and plant species for physical survival, economic and social well-being, or the maintenance of traditional culture. Subsistence use patterns in wilderness are complex and changing and, in some cases, are becoming an income-supplementing activity as opposed to a sole source of income. Nationwide, about 13% of all wilderness areas accommodated some subsistence use by rural or native populations in 1987 (Reed et al. 1989).

Spiritual development.—Wilderness is also a place where the human spirit may be enhanced, individually and collectively, through the use and exposure to nature or sacred places and things. The use of wilderness for spiritual growth has not been well researched or documented and is one of the most difficult uses to measure or value. Nevertheless, spiritual purposes are specifically acknowledged in national wilderness statutes, code, and agency policy as a significant value (McDonald et al. 1989).

Sacred places include areas that serve religious or spiritual functions and areas with capacities to inspire us, such as Yosemite or the Grand Canyon. Almost 20% of all wilderness areas across the managing agencies, and 18% of Forest Service wilderness, were reported to contain a site spiritually important to Native Americans (Reed et al. 1989). A number of organized groups use wilderness to promote spiritual growth as a stated purpose in outdoor recreation activities, including Boy Scouts, Girl Scouts, Sierra Club, National Audubon Society, and Outward Bound. Individuals likewise experience comparable spiritual growth outside organized groups, often without either planning for it or even seeking it.

Contributions to social welfare.—Recent economic research has begun to explore nontraditional ways of measuring the total benefits of the natural environment to society. Studies using contingent valuation (or "willingness-to-pay") methods now suggest that Americans also attach certain noncommodity values to the simple preservation of wilderness (Walsh and Loomis 1989).

It is a myth that only those who visit a wilderness for recreational or other purposes derive value or benefit from it. In addition to visitation, people may also indirectly derive benefits from knowledge about wilderness and its preservation. In general, a majority of Americans have reported that they consume some form of preservation values of natural areas (Walsh and Loomis 1989). Several noncommodity values have been identified for the preservation of wilderness including "option," "bequest," and "existence" values.

Research and monitoring.—Wilderness is a laboratory for the study of natural processes and the interaction of human culture and nature. As this country continues to grow and the influences of humans on the environment become more pervasive, the need to study natural processes becomes more critical. Wilderness areas provide excellent opportunities for studying natural processes and understanding how ecosystems function in the absence of human interference (Greene and Franklin 1989). Some form of environmental research was being conducted in 37% of all wilderness areas in 1987 (Reed et al. 1989). The environmental research being conducted on elements of the NWPS has been strongly influenced by the missions of the four agencies and their respective management policies and practices (Allen 1985, Franklin 1987). Ecological research is still lacking in baseline inventories of all types of wilderness areas.

Because wilderness often represents the natural environment in its most pure and unmodified form, it offers excellent opportunities to study individual and collective human relationships with nature (Manning 1989). Social research may include investigations into recreational, cultural, spiritual, physical, and psychological interactions, to name but a few. Products of social research in wilderness are useful for a number of reasons. Foremost, social research is useful in improving the management and preservation of wilderness because only human-induced impacts have the potential to destroy wilderness character.

Monitoring in wilderness serves to measure and document background information and changes for all types of land as well as to preserve the legally mandated integrity of the wilderness area itself or others compatible to it. However, because of expense and perceived impact, and because their usefulness is often not immediate, environmental monitoring activities are often ignored. The general pattern of environmental research among the four federal agencies also holds true for environmental monitoring.

Education.—Wilderness is, in one respect or another, a classroom for everyone. Wilderness education helps to achieve two goals of the Wilderness Act: (1) provide for the enjoyment of users, and (2) protect the resource. Formal and informal educational or interpretive programs may help visitors to gain deeper understanding of the special qualities of wilderness and its natural processes. Such programs not only help visitors to recognize the unique opportunities in wilderness use but also to appreciate its fragility. As a result, educated visitors often have less impact on the environment and help to keep wilderness untrammeled. More than 37% of all wilderness areas hosted some type of environmental education program in 1987 (Reed et al. 1989). About 11% of all wilderness areas showed some increase in such activity in the past 3 years.

The wilderness setting also offers unique opportunities for training wilderness resource managers, which was one of the five major action items identified in the 1983 National Wilderness Management Workshop in Idaho. Field-based wilderness "classrooms" provide skills training and resource sensitivity in addition to resource training (Spray and Weingart 1989). A survey showed that 12% of all wilderness areas hosted some type of resource manager training in 1987 (Reed et al. 1989)

Nonconforming uses.—Several nonconforming commercial commodity resources may be consumed or extracted within wilderness boundaries where they were legitimate uses prior to wilderness designation. The most common commercial uses permitted in wilderness are grazing, mining, and outfitting and guiding services.

A survey indicated that 44% of all wilderness areas had active commercial outfitting or guiding services in 1987 (Reed et al. 1989). In 1987, 35% of all wilderness areas reported active cattle or sheep grazing allotments. Another 9% of wilderness areas reported active surface or subsurface mining claims in 1987. And, about 1% of all wilderness areas reported active producing oil or natural gas wells that year.

Over the past 3 years, the level of commercial uses in most wilderness areas has generally been stable. Most wilderness areas experienced slight decreases in grazing and mining and most saw commercial outfitting and guiding services increase somewhat.

In addition to commodity resources that are consumed within wilderness boundaries, wilderness often cleanly and cheaply produces a wide range of valuable commodity and noncommodity output which is eventually consumed outside wilderness boundaries. Many wilderness areas, particularly those located in mountains, are important watersheds. Water may be used in a number of recreational, agricultural, domestic, and commercial or industrial purposes. A number of fish (and wildlife) species reared in wilderness migrate out of the wilderness where their harvest contributes to local economies. Wilderness areas also provide important vegetation which produces oxygen as well as purifies polluted air.

Projections of Future Demand for Outdoor Recreation

Projections of demand for outdoor recreation were developed for this Assessment. They reflect how much Americans would prefer to recreate at a future time if opportunities and the cost of taking recreational trips away from home were to remain as they are today. Under these unconstrained conditions, projections of the public's maximum preferred future demand for land, water, and snow and ice activities were estimated for each decade to the year 2040. Within each of these three resource categories, a range of activities is covered from those which predominantly occur as dispersed use in remote wildlands to those which are predominantly development oriented.

Although subject to error caused by an uncertain future, projections reported here are well-grounded in economic theory and statistical methods. Recreation customers are the same people who buy bread at the grocery store, and they decide to recreate or not in a manner very similar to how they choose which brand and what amount of bread to purchase. These research results are offered as advancement of the understanding of recreation demand and supply. The results should be interpreted and applied using professional judgment and with due consideration of social, political, and other qualitative factors that impact outdoor recreation demand and supply (Bergstrom and Cordell 1988).

For the projected activities, there were a total of 2.7 billion recreational trips away from home and primarily destined for rural forest, range, and water areas for 1987. From this benchmark measure of current recreation demand, projections of the public's maximum preferred demand for recreational trips were developed. These projections were based on the best available assumptions about future growth of disposable personal income, its affect on percentage of the population earning real income in excess of $30,000, percentage of the population who are young adults (18 to 32), population growth, and the degree to which a variety of recreational opportunities will likely exist. These are the major factors appearing to shape future recreation demand.

Among individual activities, those projected to exhibit the most rapid rates of demand growth by the American public include downhill skiing, cross-country skiing, pool swimming, backpacking, visiting prehistoric sites, running and jogging, and day hiking (table 14, figs. 23 and 24). All of these activities are expected to rise 30% or more by 2000. They are also physically demanding and require space, trails, and access. They do not, for the most part, require extremely large capital investments on the part of resource managers. Provision of the space, trails, and access will, however, generally be a challenge for future management of public lands. While these lands, managed in cooperation with private interests, are large enough to accommodate the projected demand increases, their lack of proximity to populated areas will be a problem.

The activities expected to grow next most rapidly include bicycle riding, horseback riding, nature and wildlife study, photography, visiting historic sites, and developed camping. All of these activities primarily involve land-based recreational trips and tend to be highly dependent upon scenic or otherwise interesting environments. For these activities, capital investment needs would be relatively small and public lands can greatly contribute to meeting demand growth.

While maximum preferred demand for trips for all activities are projected to grow, growth in demand will be slower for some activities than for others. Activities with slower projected growth of trip demand by the year 2000 include nature study, driving vehicles or motorcycles off-road, picnicking, stream/lake/ocean swimming, and motorboating. For the most part, these activities are less physically active and to a greater degree involve motor-driven equipment. These activities typically require the designation of special places and "use zones" to facilitate participation.

Table 14.—Maximum preferred demand for recreational trips away from home and indices of future demand growth to 2040.

Resource category and activity	Trips in 1987 (millions)	Future number of trips as percentage of 1987 demand				
		2000	2010	2020	2030	2040
Land						
Wildlife observation and photography	69.5	116	131	146	162	174
Camping in primitive campgrounds	38.1	114	127	140	154	164
Backpacking	26.0	134	164	196	230	255
Nature study	70.8	105	113	120	131	138
Horseback riding	63.2	123	141	160	177	190
Day hiking	91.2	131	161	198	244	293
Photography	42.0	123	143	165	188	205
Visiting prehistoric sites	16.7	133	160	192	233	278
Collecting berries	19.0	113	126	143	166	192
Collecting firewood	30.3	112	124	138	157	178
Walking for Pleasure	266.5	116	131	146	164	177
Running/jogging	83.7	133	163	197	234	262
Bicycle riding	114.6	125	148	173	202	222
Driving vehicles or motorcycles off-road	80.2	105	111	118	125	130
Visiting museums or info. centers	9.7	118	136	153	174	188
Attending special events	73.7	114	127	141	157	168
Visiting historic sites	73.1	122	143	169	203	241
Driving for pleasure	421.6	115	128	142	157	167
Family gatherings	74.4	119	135	152	170	182
Sightseeing	292.7	118	136	156	183	212
Picnicking	262.0	108	117	126	136	144
Camping in developed campgrounds	60.6	120	137	155	173	186
Water						
Canoeing/kayaking	39.8	113	126	140	157	169
Stream/lake/ocean swimming	238.8	105	110	117	124	129
Rafting/tubing	8.9	111	136	164	215	255
Rowing/paddling/other boating	61.8	112	124	136	150	159
Motor boating	219.5	106	111	117	123	127
Water skiing	107.5	111	121	131	141	148
Pool swimming	221.0	137	169	205	242	269
Snow and ice						
Cross-country skiing	9.7	147	177	199	212	195
Downhill skiing	64.3	153	197	247	298	333

Source: 1985–87 Public Area Recreation Visitor Survey.

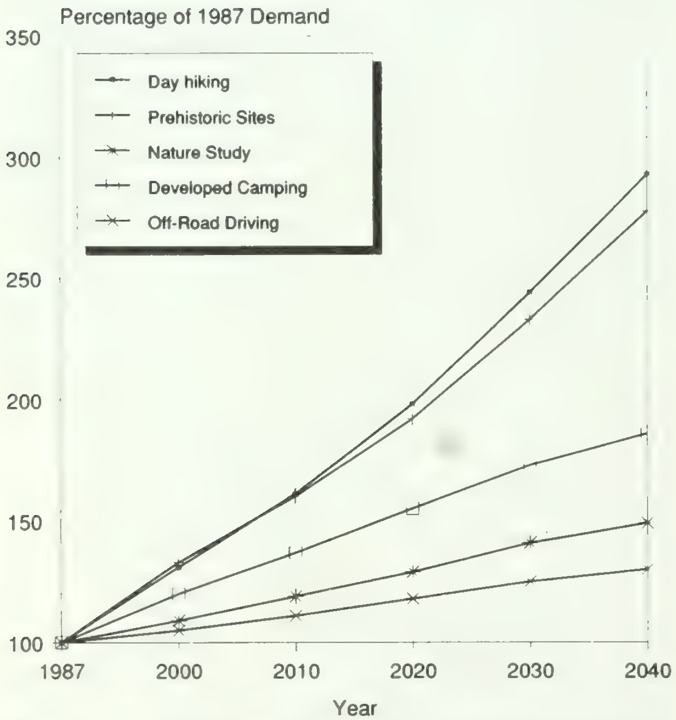


Figure 23.—Projected demand growth for selected LAND-BASED outdoor recreational activities, 1987 = 100%.

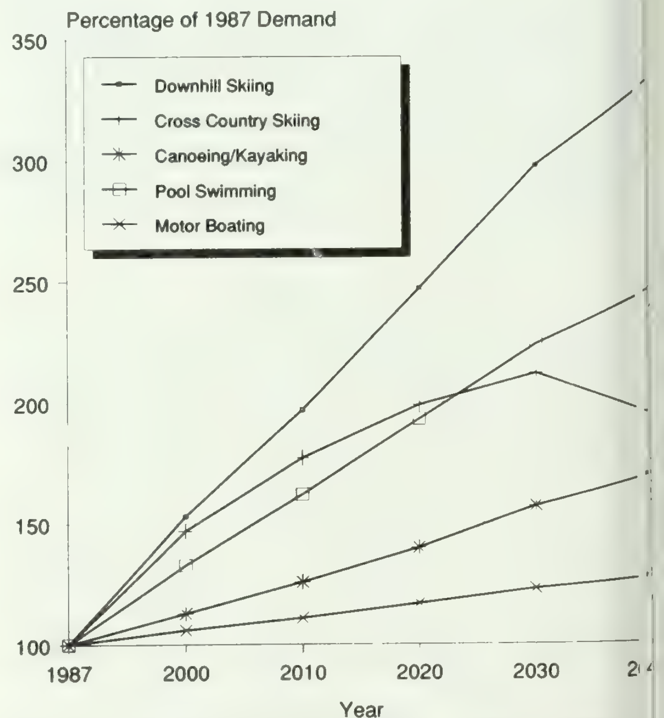


Figure 24.—Projected demand growth for selected WATER- and SNOW-BASED outdoor recreational activities, 1987 = 100%.

Currently, the 11 activities that are expected to exhibit he **greatest growth in number** of recreational trips away rom home in the future, in order from greatest to least, nclude: walking for pleasure, driving for pleasure, icnicking, stream/lake/ocean swimming, family gatherngs, pool swimming, wildlife observation and photogaphy, other outdoor photography, motorboating, icycle riding, and day hiking. The top eight of these ctivities, which involve over 35% of all outdoor recreaional trips away from home, are predominantly passive, ow-impact, and require little capital investment by site nanagers. The last three activities require some faciliies including trails.

By 2040, if average cost per trip does not change and pportunities are expanded, participation would change s shown below. Activities are arranged from highest to owest number of trips.

	Million trips	Percentage change
Driving for pleasure	704	+ 67
Sightseeing	620	+ 112
Outdoor pool swimming	594	+ 169
Walking for pleasure	472	+ 77
Picnicking	377	+ 44
Stream/lake/ocean swimming	308	+ 29
Day hiking	267	+ 193
Bicycle riding	254	+ 122
Visiting historic sites	176	+ 141
Family gatherings	135	+ 82
Wildlife observation and photography	121	+ 74
Camping in developed campgrounds	113	+ 86
Photography	86	+ 105

If the predicted percentage growth occurs, these 13 activities will account for a total of more than 2 billion additional trips away from home by 2040. Significant shifts in types of recreational trips are apparent from the above lists. Sightseeing and driving for pleasure are projected to be the most popular activities by 2040. These shifts assume that the public's demands for space and facilities can be met in future years. Pool swimming, day hiking, bicycle riding, family gatherings, picnicking, and stream and lake swimming will become dominant day-use activities. More developed facilities will be needed to serve these demands. More camping sites will also be needed. At the same time, there will be a high demand for sightseeing, walking, pleasure driving, and photography. Many of these activities depend upon high quality scenery and access. Some depend upon specialized facilities.

The growth rates of maximum preferred demand vary among activities. Land-based activities have highly variable projected rates of growth, ranging from a low of 30% to 2040 for off-road driving to a high of 193% for day hiking (fig. 23). Growth in demand to 2040 for water and snow activities is also quite variable, ranging from 27% for motorboating to 233% for downhill skiing (fig. 24). These very different growth rates indicate the magnitude of predicted demand shifts in the future and point to a likely shift of pressures on recreational resources and management. While these projections may not be precise, they do, nonetheless, provide insights and offer the opportunity to anticipate rather than react to demand shifts.

Although much less quantitative, growth of wilderness use seems highly likely. Recreational uses have shown reduced growth rates, even decreases for some

Sightseeing and driving for pleasure are projected to be the most popular outdoor recreation activity in 2040. Pool swimming, day hiking, bicycle riding, family gatherings, picnicking, and stream and lake swimming will become dominant day-use activities.

areas, in recent years. However, since 1986, an upturn of recreational wilderness use once more seems to be occurring. And, based on projected futures for activities which commonly occur in wilderness, demand increases seem evident. For example, backpacking is projected to grow 155% by 2040, wildlife observation and photography 74%, day hiking 193%, and general outdoor photography 105%.

Future demands for nonrecreational uses of wilderness are less clear, although indications are for an upward trend. Participants at the 1988 Wilderness Colloquium, all experts on wilderness resources, indicated that future nonrecreational uses and values may soon dominate over recreational uses. Increasing environmental concern, needs for biological monitoring, decreasingly available undisturbed spaces, and other trends strongly support a prediction for demand growth of nonrecreational uses.

CHAPTER III: THE SUPPLY OF OUTDOOR RECREATION AND WILDERNESS

The Supply Concept

The concept of **recreation demand** was discussed in the introduction to chapter II and was defined as the number of recreational **trips** people will take after they have considered the costs those trips will entail. To be consistent in our analysis in this chapter and to meet this Assessment's objective of examining population-level wants for recreation opportunities and experiences, rather than demand for access to a specific facility or category of sites, supply must be similarly defined. We must, therefore, examine the **supply of trips**, rather than supply of sites or facilities, as the appropriate measure of recreation supply.

The supply of recreational trips is more complex as a concept than is the supply of recreational facilities or most other commodities or services. This complexity arises because a recreational trip is not purchased as a tangible good or discrete service directly from a retail or wholesale establishment. A further complication arises because a significant portion of the recreation opportunities in this country are provided by the public sector. Here, classical production processes, as described in the economics literature, typically do not apply.

A recreational trip involves the total experience as first defined by Clawson and Knetsch (1971). Using this definition, a trip involves not only an on-site visit at a facility, but also anticipation, travel, and recollection. Thus, the consuming household and the recreation site manager are involved in the "production" or supply of a recreational trip or experience. Application of traditional economic analysis aimed at detecting probable shortages of recreational trip opportunities for the American public can fail unless the involvement of the recreationist as a part of the production process is taken into account.

The mismatch in definitions between the opportunities that the forest or park manager provides and the trips or experiences that recreationists demand has long been a source of confusion. This has especially been the case when the target for demand and supply comparisons has been at the national or regional level rather than at the site level. At the national or regional level, the concern is whether sufficient opportunities for outdoor recreation trips are being provided to meet population demands. At the site level, the concerns are typically with construction of new facilities, how much capacity to provide, or sometimes whether to operate a site at all. These two different levels of concern involve quite different questions and quite different demand and supply comparisons.

In recent years, a workable framework for national- and regional-level demand and supply comparisons has come to light. This framework, the household market model, as originally described by Bockstael and McConnell (1981), was adopted for this Assessment to explicitly recognize the role that households play as part of the recreation trip production process (Cordell and Bergstrom 1989). Since a trip is also the unit that the recreationist demands and, subsequently, consumes, the necessary conditions for an economic comparison of demand and supply is met.

The household market model defines two steps or stages in production of recreation supply on a national or regional level. In the first step, public and private managers and proprietors develop and manage land, water, and other resources to make different kinds of environments and opportunities available for public recreational use. In the second step of recreation production, the household combines the environments and opportunities provided by managers and proprietors in the first step with their own knowledges, skills, abilities, equipment, travel, and technology to produce recreational experiences or trips. New technology and equipment, such as hang gliders, help make new kinds of recreation experiences—they help create new supply. In the case of hang gliders, this new technology has brought increased management attention to cliffs with updrafts, many of which are now treated as recreational environments. Recreation skills courses and new information about the locations of public sites may also lead to production of more recreation trip supply.

In this chapter, the supply of recreation is presented from the perspective of this two-step production process. First, the resource and facility inventory of chapter I is reexamined here to measure how effective their amounts and locations are relative to the numbers and locations of the populations who may want to use them. Taking account not only of the amount of facility and resource opportunities but also of their location, as well as the location and number of potential users, more accurately reflects available opportunities. Availability of opportunities is an important factor determining trip production (i.e., supply).

Second, recent trends of the amount of recreational environments and facilities, as provided by both the public and private sectors, are described. Factors affecting trends in the availability of recreational opportunities are also discussed as a prelude to speculating about possible supply futures. Third, a brief discussion of likely future trends in recreational opportunities, assuming recent trends continue, is provided as a step toward anticipating future supply. The supply of opportunities for recreational trips and experiences is projected for each decade to the year 2040. The conditions and implications of these projected futures are briefly discussed. Finally, current availability, recent trends, and likely future supply of wilderness use opportunities are presented.

Understanding the supply of wilderness is even more complex than that of recreation. Recreational use of wilderness is subject to the same considerations as recreation outside of wilderness. However, the nonrecreational uses of wilderness are many, and hard data on consumption and demand are lacking. As a consequence, the national demand for wilderness in most

cases is politically expressed. Accordingly, classical economic supply considerations, beyond per capita figures, are mostly qualitative.

Effectiveness of the Amount and Location of Available Recreational Opportunities

Recreational opportunities are widely available to Americans, but their type and quantity are unevenly dispersed among and within regions across the country. Remote backcountry areas are heavily concentrated in the West. Developed sites are generally more evenly distributed between West and East, yet more people live in the East to compete for use of these relatively scarce opportunities. An unevenness of available opportunities also occurs within regions. Some local areas have many more opportunities than others, and often the opportunities in some local areas are more conveniently located near population centers. These two factors, amount of opportunities available relative to numbers of people and location of these available resources relative to location of people, define the effectiveness of opportunities.

The effective amount and location of available recreational opportunities, from remote wildlands to developed environments, is highly variable nationwide. This variability is important when considering the supply of outdoor recreation. Improvements in supply may be affected by changes in the sheer quantity of land and water available for recreation in a region as much as they may be affected by overall shifts in the location of opportunities relative to where people live. The more effectively that recreational opportunities are made available relative to numbers of people and their location within a region, the more trips residents of a region can take without expending more time and money to "produce" the average trip.

Another important factor affecting a person's or household's level of trip production for a specific type of recreation is the availability of other types of opportunities which may compete for scarce personal time and money. Here, amount and location of alternative opportunities is a most relevant consideration. As alternative or substitute opportunities become more abundant and/or conveniently located and, thus, as substitute trips become relatively less expensive to produce, there may be less of some particular types of recreational trips taken by households.

In the supply analysis which concludes this chapter, effectiveness of the mix of recreational opportunities available is a vital consideration in the household production process. In that analysis, it is shown that the effective quantity and location of recreational opportunities have important effects on the supply of particular types of recreation. The following brief sections point out some of the more striking interregional and intraregional differences in effective recreational opportunities.

Land-Based Opportunities

The more densely populated states are located in the East (fig. 25). Less than 5% of federal recreation lands

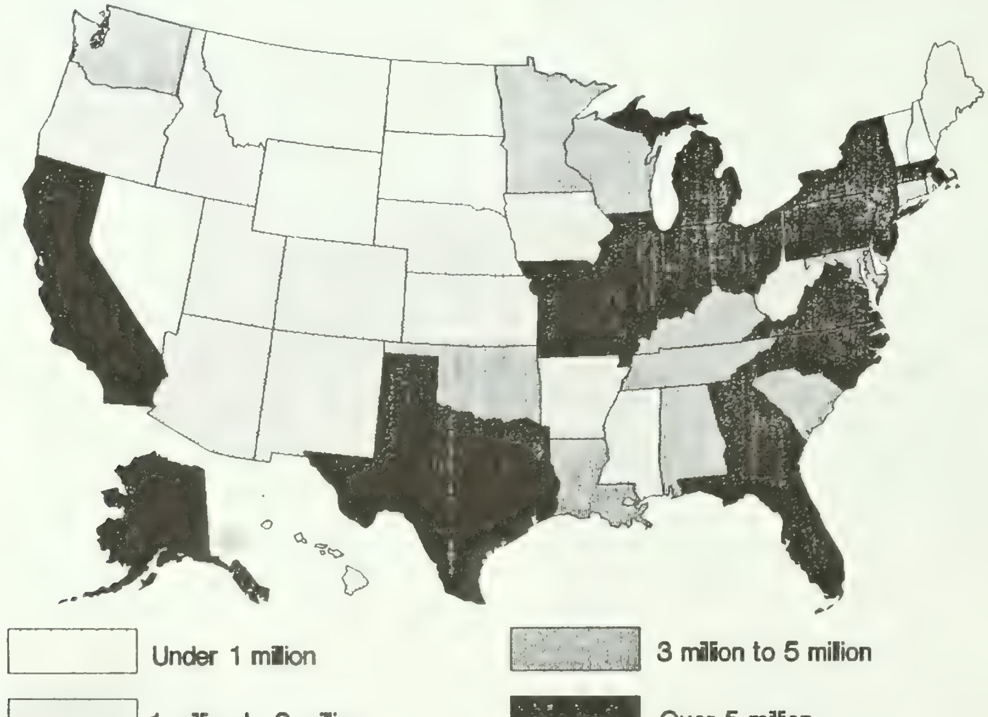


Figure 25.—Distribution of population by state.

(excluding Alaska) are located in this region. State and local lands help some to make up for the lower quantity of federal properties in the East, but they typically offer a different kind of recreational opportunity. Two-thirds of nonfederal public and private lands are east of the Rockies. Also, state and local lands generally are located closer to cities.

Even with the much greater prevalence of state, local, and private lands in the East, the disparity in per-capita availability of recreational opportunities between the West and East is extreme. Measured as an effectiveness index, which takes into account the amount of resources, number of people, and location of resources relative to location of people, opportunities linked to land resources are typically 5 to 15 times greater in the Pacific Coast and Rocky Mountain Regions than they are in the Northern and Southern regions (figs. 26–29).

The effective availability of wilderness and the most remote of recreational opportunities (fig. 26) is about 15 times greater in the West than the East. Forest Service and BLM lands largely account for this regional mismatch between locations of opportunities and of people. In the East, limited remote and wilderness opportunities are most effectively available in Florida, Minnesota, Wisconsin, and in upper New York State. Effective availability of less remote backcountry (0.5 to 3 miles from roads) is much greater in the East than is remote wilderness (fig. 27). Few areas in the East lack backcountry opportunities. But, as with wilderness opportunities, much greater availabilities exist in the western states.

Roaded and partially developed land opportunities (those within 0.5 mile) are the areas where most of the resource-based outdoor recreation in the United States occurs. Because some private land is still accessible, the effective availability of these more convenient land opportunities in the East is substantially greater than the more remote types of opportunities. Typically, absence of availability coincides with large population concentrations such as the area from Richmond to Boston (fig. 28). Combinations of roaded public and accessible private lands in the West, except for the southern two-thirds of California, provide highly effective road-accessible opportunities. Developed recreation, in contrast to other land opportunities, is the most evenly distributed of opportunities (fig. 29). In the West, the least effective availability relative to numbers and location of population is southern California, most of Texas, and parts of Kansas. Less effective availabilities of developed land opportunities in the East exist in the lower Mississippi subregion, in the Piedmont Crescent subregion from Richmond through Atlanta to Birmingham, and in the Cincinnati area.

Water-Based Opportunities

Though common apprehensions foster images that industrial pollution creates unsafe water in urban areas, there are, in fact, many fishable and swimmable water areas in or near major population centers. In 1986, the Environmental Protection Agency estimated that about three-quarters of this surface water was clean enough for fishing and swimming (Domestic Policy Council 1988). Further clean-up efforts may greatly expand water-based recreation opportunities. These efforts will have the greatest impact in areas of high population density where waters tend to be privately or municipally owned and historically have been the most heavily polluted (Domestic Policy Council 1988).

Though more resources for water recreation than for land recreation are located near population centers, a large East-West disparity still exists. The most remote of water recreation opportunities, such as Wild and Scenic Rivers, are five to eight times more abundant in the West (fig. 30).

Areas in the West that have the greatest amount of road accessible and developed water opportunities generally have two to six times the opportunities that areas with less abundant opportunities have (figs. 31, 32 and 33).

Snow and Ice-Based Opportunities

The distribution of winter recreation opportunities across the United States follows temperature gradients, elevational differences, and snowfall areas. Snowfall in the northern states and at higher elevations convert recreationally available land areas into snow opportunities for skiing, snowmobiling, snowshoeing, and other winter activities. Effectively, the western regions have about 12 times more remote, wilderness, and backcountry snow opportunity than does the North (figs. 34 and 35). The South, of course, has virtually none, except for the southern Appalachian area. Road-accessible snow opportunities and developed winter recreation sites differ less between West and North by about 7 to 1, respectively (figs. 36 and 37).

Recent Trends of Resource Availability

The single most critical factor determining the degree to which recreation opportunities are being offered to the public is available access, both to land and water resources and to facilities and development specific to certain types of outdoor recreation. This Assessment focuses on those resources and developments which are available. Since 1970, the amounts of resources available have changed, some dramatically so. Following is a brief overview of recent trends (1970–1987) of resource availability.

Land Resources

Though land designated as wilderness has increased, road building and other land conversions have decreased recreation opportunities in remote backcountry environments, of which wilderness is a part. In 1987, 326 million acres of land were farther than 0.5 mile from a road. In the years, from 1970 to 1987, the amount of this remote land resource decreased about 2.9 million acres annually, or 0.9% per year.

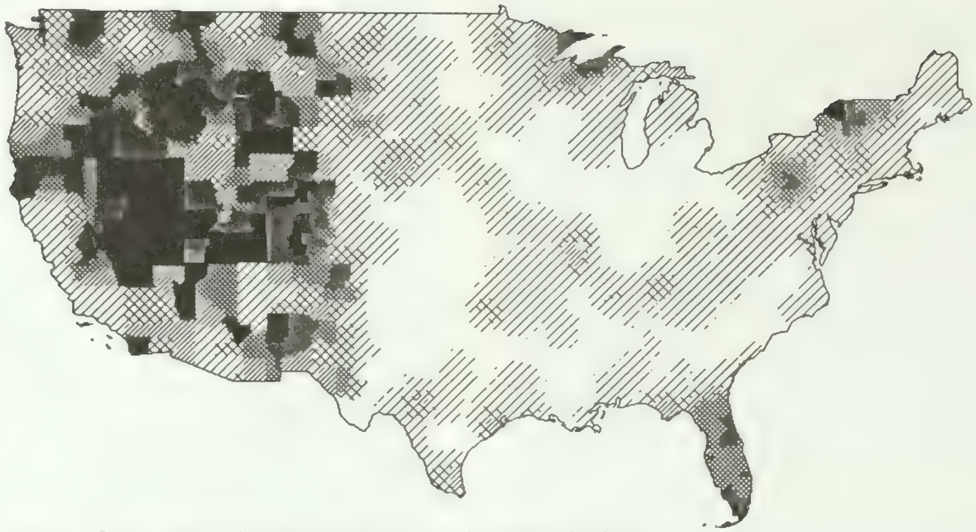


Figure 26.—Comparison of effective amount and location of wilderness and remote backcountry opportunities in the United States, 1987.

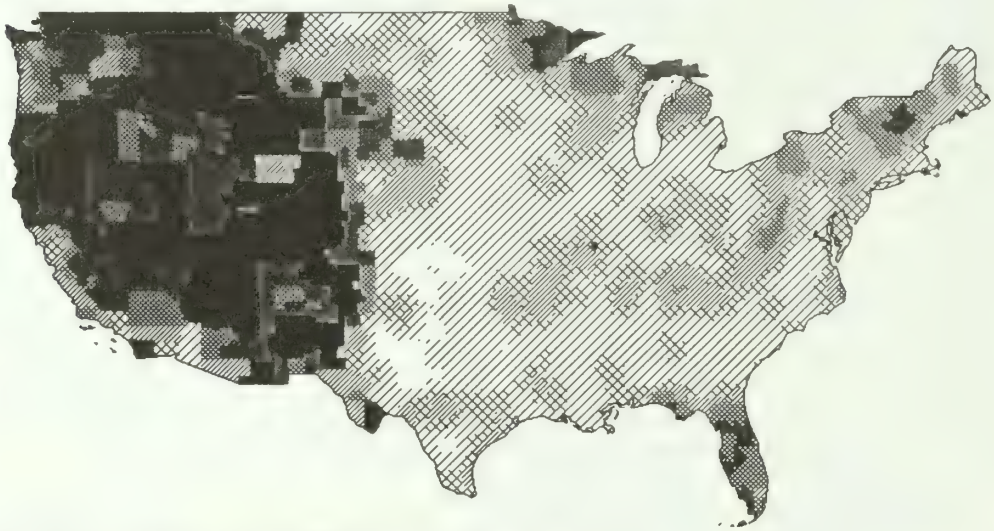


Figure 27.—Comparison of effective amount and location of extensive undeveloped land opportunities in the United States, 1987.

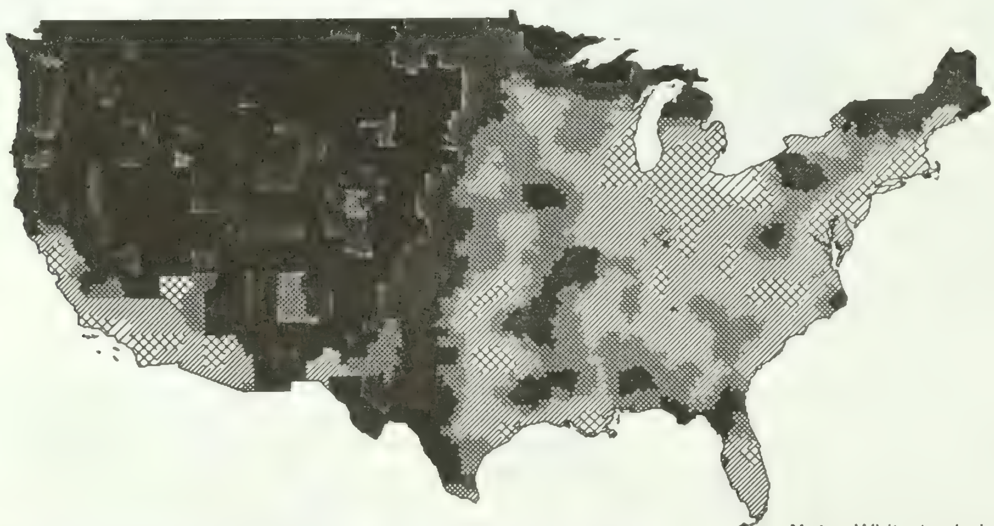


Figure 28.—Comparison of effective amount and location of roaded, partially developed land opportunities in the United States, 1987.

Note: White to darker shadings indi[illegible]
opportunity. Effectiveness of opportuni[illegible]
location relative to the number and [illegible]

Figure 29.—Comparison of effective amount and location of developed land opportunities in the United States, 1987.

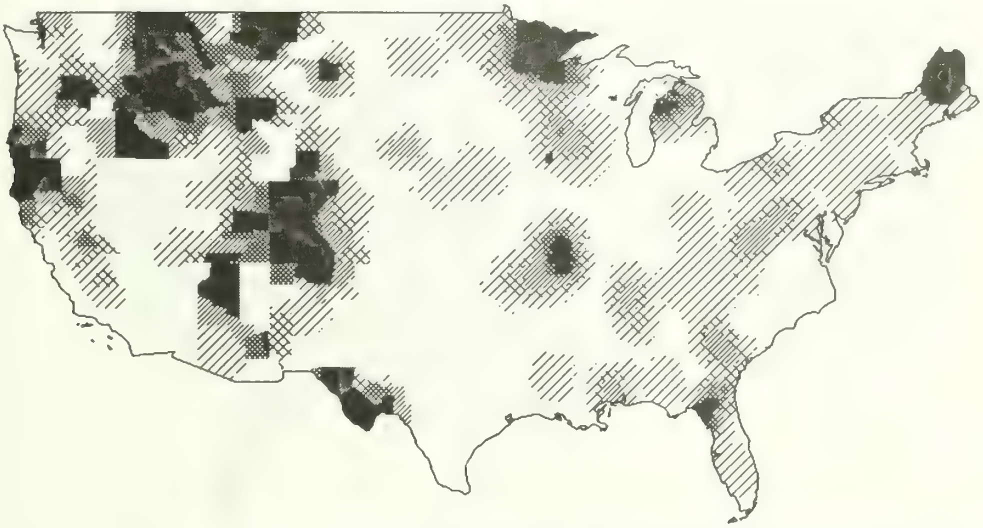
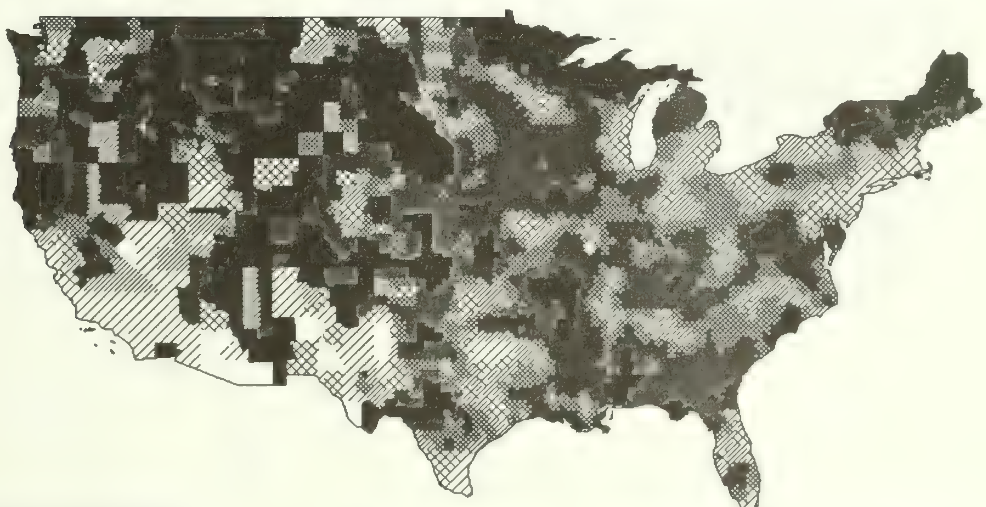


Figure 30.—Comparison of effective amount and location of wild, scenic, or remote water opportunities in the United States, 1987.



...sively higher levels of effective recreational ...nty, state, or region refers to its amount and ...ain as potential users of the opportunities.

Figure 31.—Comparison of effective amount and location of near-road lake or stream opportunities in the United States, 1987.

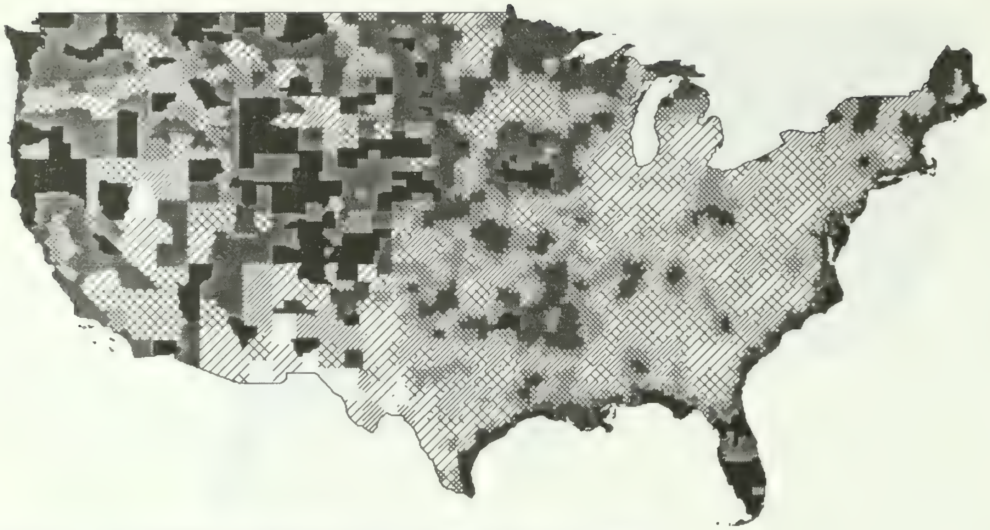


Figure 32.—Comparison of effective amount and location of partially developed lake or stream opportunities in the United States, 1987.

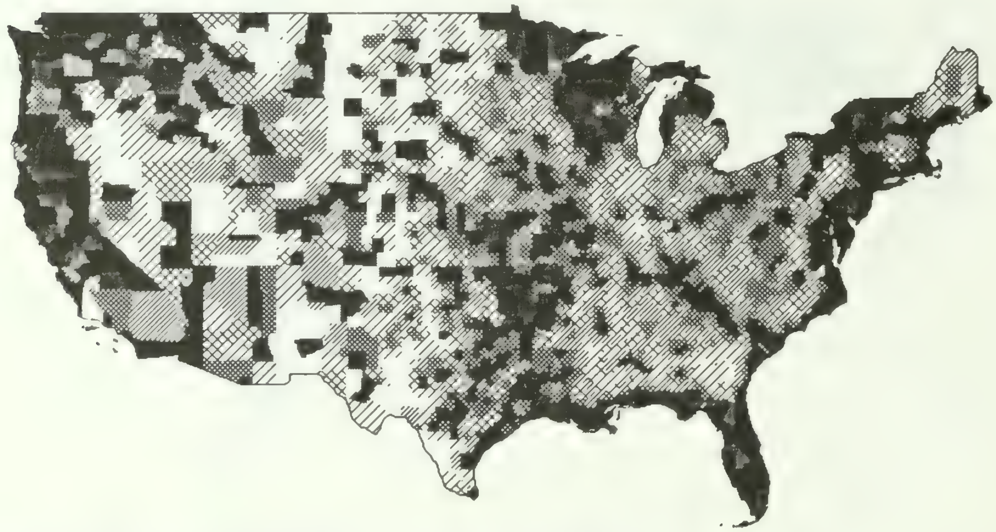


Figure 33.—Comparison of effective amount and location of developed water opportunities in the United States, 1987.

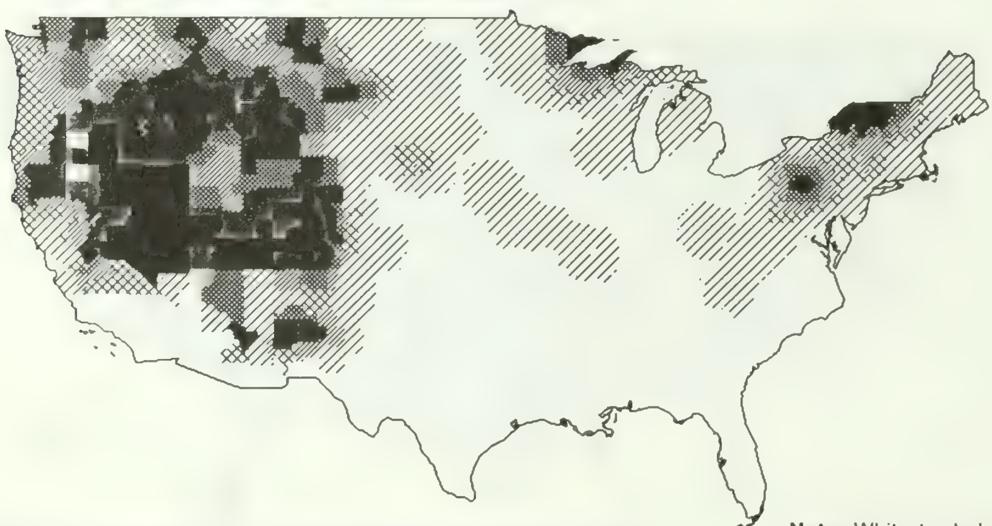


Figure 34.—Comparison of effective amount and location of wilderness and remote winter opportunities in the United States, 1987.

Note: White to darker shadings ind[illegible] opportunity. Effectiveness of opportuni[illegible] location relative to the number an[illegible]

Figure 35.—Comparison of effective amount and location of near-road, undeveloped winter opportunities in the United States, 1987.

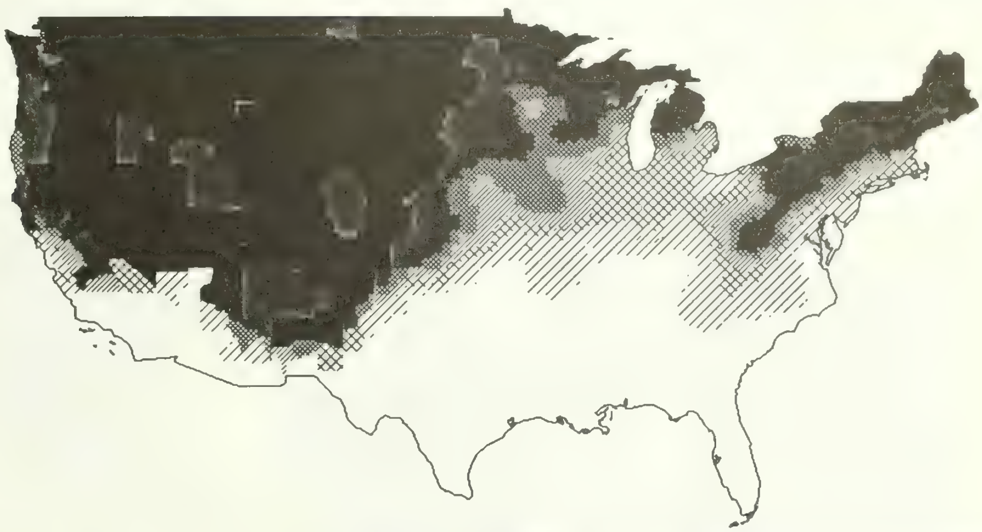


Figure 36.—Comparison of effective amount and location of roaded, partially developed winter opportunities in the United States, 1987.

e ively higher levels of effective recreational
ty, state, or region refers to its amount and
on as potential users of the opportunities.

Figure 37.—Comparison of effective amount and location of developed winter sports site opportunities in the United States, 1987.

Roaded forest and rangeland recreation opportunities also have been decreasing. In 1987, 720 million acres were within 0.5 mile of roads. Since 1970, the average annual decline in this category has been about 5 million acres, or 0.7% per year. The reverse is true of developed recreational opportunities, such as picnic areas, campgrounds, nature centers, golf courses, and other recreational sites. Across all levels of government and in the private sector, developed land-based recreational opportunities have been increasing at about 0.6% per year.

Water Resources

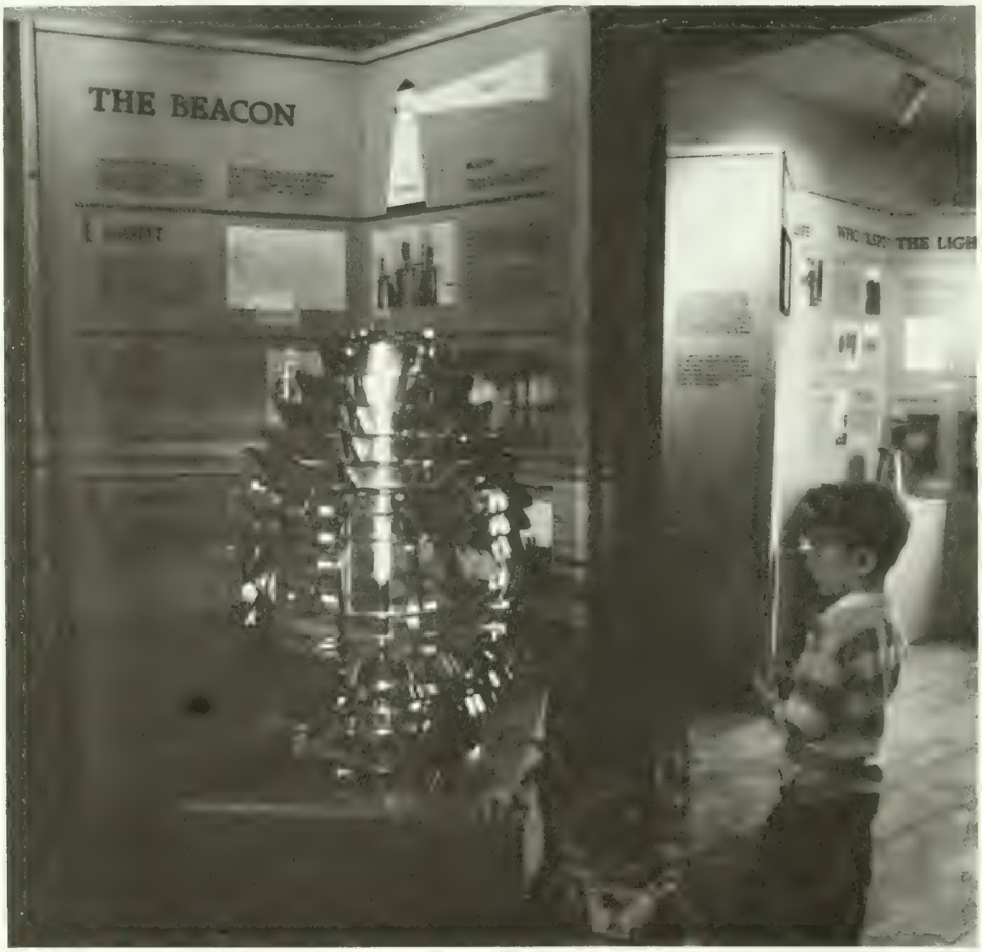
Since 1970, remote wild water available for recreation has increased slightly, at about 0.3% per year. This is in contrast with water areas adjacent to road access which have decreased at about the same rate over the last few years. Declining access has been responsible. The greatest increase occurred in highly accessible water recreation opportunities and developed water sites which grew between 0.5% to 1% per year. The growth of these opportunities reflects construction of launch ramps, bridges, equipment development, piers, and other developments and access improvements. This growth, however, has been slower than popu growth.

Snow and Ice Resources

Recent trends indicate gradual reductions in tl capita amounts of roadless, remote land in areas snowfall is sufficient for winter sports. Additio roaded and partially developed areas where suff snowfall for recreation occurs have also been de ing, primarily because of private land closures. I oped winter sports sites, however, have been incre fairly rapidly since 1970, but at a decreasing r growth. In the 1970's, growth occurred through ne development. Since the late 1970's, growth has la occurred through better management and technol increase capacity. For example, since the early 1! growth in ski lift capacity has been about 1.5% per

Other Factors Influencing Recreation Opportunities

Access, information, budgets, and private servic additional factors influencing the availability



Access, information, budgets, and private services all influence the availability of recreation resources.

sources and, thus, the amount and nature of opportunities the American public has or will have for outdoor recreation.

Access

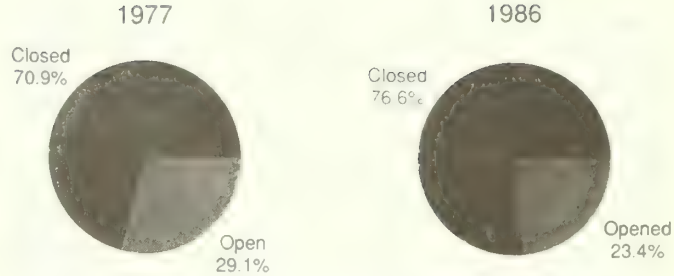
Several factors have broadened the availability of this country's public lands: the expansion of the interstate highway system, more frequent and lower cost air travel, better travel information and services, and more fuel-efficient automobiles, as well as growth in the tourist industry. But, practical constraints limit the availability of much public wildlands so recreation participation is often light, especially on federal lands (Domestic Policy Council 1988). Along with state and local governments, private landowners make an important contribution in providing recreational opportunities near urban areas where federal opportunities usually are quite limited. This does not mean, however, that all federal lands are difficult to access. Some national forests and national parks are located near or even within urban areas. But these federal and state areas usually are not adequate to meet all recreation demands, which highlights the importance of private lands.

Private nonindustrial land.—The portion of total nonindustrial private acres reported open for public recreation decreased from about 29%[6] in 1977 to about 23% in 1986 (fig. 38). Currently, 283 million private acres are open to public access either for free, a fee, or lease. One can attribute this trend toward ownership for exclusive uses to the decline of acreage, perceived threats of liability suits, needs for privacy, and competing land uses (Wright et al. 1989). Absentee ownership and previous bad experiences with public use have encouraged posting. Also, fragmentation of the land base into smaller tracts has made land availability contingent upon an increasing number of owners (Cordell et al. 1985).

To encourage private owners to provide access, 46 states have implemented legislation protecting against liability suits except in cases of gross negligence. Many of these statutes have not been tested in court, and owners who charge fees for access usually are not protected. So far, owners have been reluctant to take advantage of the statutes (Domestic Policy Council 1988). In addition, among owners who would be willing to open more land, revenues from fees or leases or tax incentives rank higher than protection from liability as incentives for providing more public access. Nationwide, about 4% of private nonindustrial land (53 million acres) is leased, although lease or fee arrangements are a rapidly rising trend, almost doubling every 5 years. Hunting seems to be the overwhelming recreational activity in lease arrangements; but, horseback riding, camping, and fishing, among others, are increasingly involved.

Private industrial forest lands.—Generally, little information exists on the availability of industrial lands for recreation. A study reported by Resources for the Future (1983) indicated that forest industries held title or managerial control to 68 million acres nationally. This

[6]*This figure does not include leased acreage.*



Forest and range acres open for recreation

Forest, range, and cropland acres open for recreation

SOURCE: USDA Forest Service, 1980; and NPLOS, USDA Forest Service, Athens, GA, 1986.

Figure 38.—Percentage of nonindustrial private land open for recreation, 1977 and 1986.

figure had changed little since 1960 when 97% of industrial forest land was open to the public for recreation. However, by 1977, that figure had fallen to 58% (Cordell et al. 1985). During the mid-1960's, industrial forest lands began to shift from being open free of charge to charging an entry fee to help cover costs associated with public recreation. Currently, most of the access is available through leasing.

Water and shorelines.—Private ownership limits access to shorelines. This is particularly true in the East where public access to freshwater lakes and ocean beaches is usually inhibited by private owners who have posted properties adjacent to shorelines. Complaints about excessive fees for privately-owned beach use is common up and down the eastern seaboard. Land use and liability issues, as well as a willingness to compromise the longstanding ''home-rule'' principle, will have to be resolved in order to expand access to extremely popular water-based recreation opportunities. The trend since the early 1900's has been a rapid decrease of publicly accessible shorelines as private and commercial development have boomed.

Public institutional access issues.—Chapter I indicated the variety of federal, state, and local agencies managing recreation lands. Each entity manages its lands in accordance with a particular mandate. National recreation areas (31 areas), national wild and scenic rivers (about 8,000 miles), the National Trail System (58,000 miles), and the National Wilderness Preservation System (89 million acres) constitute specifically designated subsets of the lands managed by these federal agencies. Otherwise, recreation opportunities are only part, and often a small part, of the outputs for which agencies manage their land and water.

In general, federal lands offer opportunities of a primitive nature. The U.S. Fish and Wildlife Service and the National Park Service are the most extreme in this regard, prohibiting (in most instances) snowmobiling and other activities which require motorization or development. The Forest Service and the Bureau of Land Management (BLM), on the other hand, manage their lands for a broad spectrum of opportunities and purposes.

The BLM administers its lands, most of which are western rangelands, to accommodate a variety of recreation activities, from backcountry hiking and rock hounding to off-road vehicle use. The Corps of Engineers

provides many inland swimming and boating opportunities at its projects, which are designed mostly for navigation, hydropower, and flood control. The 6 million acres of waters and lands around Bureau of Reclamation projects provide recreation opportunities in Rocky Mountain and Pacific Coast states. The Bureau manages several designated recreation areas, such as Lake Powell, which was created by the Glen Canyon Dam on the Colorado River. The Tennessee Valley Authority (TVA) manages many reservoirs originally built primarily for hydropower and flood control in the Tennessee River basin. However, boat ramps, swimming areas, docks, piers, and similar recreation-related facilities are common on TVA projects.

The mission statements of state agencies managing recreation lands embrace the same spectrum of restriction and opportunity that federal agencies uphold. The same tension found at the federal level between the opposing goals of preservation and use exists among the states. In a survey of state park mission statements, Myers and Green (1989) found that the words "development" or "improvement" were mentioned as often as recreation. Historically, the emphasis at the state level has been to provide broad use at the expense of preserving undisturbed natural areas. In some states, this emphasis has shifted in recent years. Some states have established natural resource conservation areas accessible only for passive recreation (Myers and Green 1989). Counter to this movement is the thrust by several state park systems to develop more of their parks as tourist attractions in order to enhance state economies.

Institutional constraints on recreational activity vary with the administering agency. Such policies may limit access—and, therefore, opportunity—to varying degrees and function in much the same way that posting by a private landowner prohibits certain uses.

Private Sector Activities on Public Lands

The public sector has encouraged private investment in recreation facilities and services on public lands. Private enterprise has almost completely taken over some kinds of recreational opportunities, usually those that require the most development. Special use permits, leases, and concessionaire contracts are some of the alternative vehicles being used to set up private operations on public land. Downhill skiing is a good example. Private resorts operate on public lands (primarily national forests) in the majority of cases.

Providing recreation opportunities on public land has made the private sector a management partner with public agencies. In this fiscally conservative era, such joint ventures are growing. In wilderness and backcountry settings on public lands, private outfitters provide most of the services. For example, the major concessionaire in Yosemite National Park has operated a series of backcountry "High Sierra Camps" for years during the summer season. These camps offer lodging in tent cabins (which are removed in the fall), showers, and food for hikers who pay for the rustic comfort. Growing numbers of public campgrounds have been placed under man- ment of private concessionaires, and guide and ou- ter services leading tours into remote scenic areas h become popular. In another example, the Appalach Mountain Club operates a series of hostels along t Appalachian Trail in the White Mountain Natio Forest, New Hampshire.

Information

Disseminating information about recreation oppo- nities expands resource awareness and use. Informat gives potential users ideas and increases th enthusiasm about activities or sites which they may le about. Growth in the tourism industry and the my computer information services indicate that informat about recreation opportunities is available and growi

Respondents to a survey for the President's Comm- sion on Americans Outdoors (1986), however, ci word of mouth and newspapers as their major sour of information about recreational opportunities. In- mation from recreation areas and providers was ci only as a minor source. As the Domestic Policy Coun (1988) pointed out, "response may indicate that largest demand for better information is for outd recreation opportunities closer to home which gener are not addressed by the tourism industry and tra services except in the weekender section of lo newspapers."

Public Agency Budgets for Recreation

In 1986, the federal budget for "recreational sources" was about $1.5 billion (1986 constant dolla The federal budget for recreation peaked in 1978 at $2 billion dollars (1986 constant dollars) but has stead decreased since. The same trend has been true of st park and recreation budgets. They decreased in r dollars at an increasing rate between 1978 and 198

Local government expenditures, however, have ac ally increased by $229 million (1977 dollars) betwe 1977 and 1982. Between 1982 and 1985, local gove ment park and recreation operating budgets rose ab 26% and capital budgets rose 39% (McDonald et 1989). Growth rates varied by region. Operating budg in the South, Rocky Mountain, and Pacific Coast Regio rose rapidly, with capital budgets in the South a Rocky Mountain Regions rising most rapidly. Grow of operating budgets has been evident across all si of agencies or departments. However, capital budg grew most rapidly among local departments of the m heavily populated cities and counties.

Private Services

Many outdoor recreation opportunities come availa through private enterprises rather than public agenci or private organizations. Guides and outfitters, equi

ment rental firms, bed and breakfast operations, and interpretive services all make certain activities more accessible and attractive.

Guides, outfitters.—Through outfitters and guides, recreationists can avoid both investing in specialized or expensive equipment and planning logistical details of a trip. Guide services are especially important for access to wilderness and other extensive roadless areas. These services make larger trips possible by organizing groups. A sizeable niche exists for guides and outfitters to make backcountry recreation available to the public.

More than 1,000 guide services are listed nationwide. Most of these enterprises are located in regions suited to their services and are, therefore, concentrated in the western regions. Another avenue of access to remote recreation areas comes through the services of dude and guest ranches. In 1987, most of these (more than 250 listed) were located in the Rocky Mountain Region.

Rental firms.—Suppliers of recreation services include those who rent equipment. Recreational vehicles, canoes, and camping equipment are examples. More than one-half of the 1,750 equipment rental firms advertising in the Yellow Pages in 1986 were located in the North, and another 27% were in the South. Within the equipment rental industry, about 65% of those who specifically rent recreational vehicles were located in the eastern half of the country. Canoe rentals were concentrated in the North.

New equipment.—Off-road vehicles, including mountain bikes and snowmobiles, hang gliders, stunt kites, jet skis, ocean kayaks, and rock-climbing equipment all create new kinds of recreational opportunities, providing users with expanded access to outdoor settings and new points of view. Continuing innovation in equipment and the kind of activities people undertake will create challenges for users and resource managers alike.

Private organizations.—Some of the organizations which directly provide many general and programmed recreational opportunities include YMCA's, YWCA's, Boy and Girl Scouts, student and youth groups, conservation work skill volunteers (such as the Student Conservation Association and the Appalachian Mountain Club), and community service groups. These organizations provide recreation for its own sake and as a means to achieve other goals. While many programs target youth, others target special populations such as the handicapped or inner city residents. These organizations also provide the important functions of teaching outdoor skills and nature appreciation and developing public interest in outdoor recreation. They also supplement the supply of recreation facilities and provide access, primarily at the local level. Many of them organize activities and trips, thus, facilitating participation by their members.

A wide variety of resource protection interests are concerned with wildlife, wilderness, historic and cultural resources, urban open space, federal lands, rivers, wetlands, shorelines, and other natural resource features. In addition to education, some of these organizations monitor the management and quality of specific resources. Others, such as local land trusts, use special tools and innovative fund raising to acquire and otherwise protect natural resources. These groups also offer recreation related services such as tours and school programs which help them carry out their conservation work.

Associations of recreation enthusiasts typically promote a specific activity or group of activities. Examples include United Four Wheel Drive Association, League of American Wheelman, National Campers and Hikers Association, American Horse Council, and American Canoe Association. Often, these are partially supported by equipment manufacturers. Members learn new skills, find out about places to engage in the activity, jointly protect their interests, and are provided socializing opportunities through the organizations' programs.

Nonprofit organizations are somewhat different in that they tend to develop when a part of the population perceives a public service need. The past 30 years have shown unprecedented growth in the number of groups and members. Outdoor recreation associations have grown more than 63% since 1970.

Interpretive Services on Federal Lands

Interpretive services, including guided walks and tours, campfire programs, self-guided nature trails, slide shows, and so on, have long been associated with federal recreation areas. By the late 1970's, changing social values, strained government budgets, and the shift of public attention to other concerns all contributed to reductions in interpretive programming, especially in federal and state agencies. In the last few years, interest and attention to interpretation has resurged. Though interpretation's mission and its core definition have remained stable, its face and character have changed. Funding has decreased, providers of interpretation have expanded, and techniques and roles have shifted. Visitors have indicated a willingness-to-pay for interpretive services. Increasingly, user fees are being assessed for many types of interpretive programs. In exchange, users expect higher quality.

Reduced funding and subsequent interpretive staff reductions have increased the need for alternative means for providing these services. One major change is the increasing role of the private sector in providing such services, including interpretation on public lands. Many outfitters, guides, resort owners, and other recreational entrepreneurs are incorporating interpretive programming into their offerings. Several public agencies are strongly encouraging this role. Information about an area and an enhanced awareness of the relationship between the user and the resource increases the attractiveness of a facility or service, gives them a competitive edge, and enhances the experience of their clients.

Cooperating associations and "friend" organizations are involved more frequently in various ways to support interpretation. Volunteers and interns have increasingly replaced or supplemented full-time seasonal interpretive staff. Interpretive associations affiliated with the Forest Service, for example, have enhanced the quality of the outdoor recreation experience for many visitors

to the national forests. These associations grossed more than $1.56 million during 1986, for which the Forest Service received a direct benefit estimated at $637,469. In 1987, 39 interpretive associations were linked to the national forests all over the country. An example of how such partnerships benefit both government agencies and the public is the Laguna Mountain Volunteer Association. Members have donated 20,000 hours to improve trails, campgrounds, and visitor services in a national forest.

Projections of Recreation Supply

This chapter opened with a brief explanation of the process by which households or individuals are involved in supplying recreational trips or experiences. First, through investment and management, agencies, private landowners, private service entrepreneurs, and other resource managers or service vendors provide various forms of outdoor recreational opportunities. Second, households combine these opportunities with their knowledges, skills, abilities, equipment, and technology to "produce" recreational trips or experiences. A camping trip, for example, requires a campground, tent, lantern, camping skills, transportation, and other inputs. A white water float trip requires a raft, the white water river, knowledge of river running, life preservers, travel, and other equipment and services.

The land, water, and snow and ice resources described in chapter I and the trends indicating changes in their availability for outdoor recreation are integral factors determining recreation supply. Changes in access, budgets, organizational involvements, services, and many additional factors influence recreation supply trends. If those trends continue, they will have imp tant effects on future outdoor recreation opportunit

For supply analysis of this Assessment, the assur tion is made that a continuation of recent trends is most likely future for recreational resources, barring unforeseen or planned change that would influe these trends. Using the best available estimates of th trends, the rates of change reported earlier were dev oped for land, water, and snow and ice resources. Th estimated rates of change were based on such kno trends as wilderness designation, forest road constr tion, ski lift capacities, private land access, and recr tion site development. As the availabilities of la water, and snow and ice resources change, so do number and types of recreational trips taken by hou holds and individuals. An increased availability resources represents increases in opportunities, in wh case, more trips can be taken at the same or lower c sumer costs per trip. On the reverse side, decreases availability mean more travel, time, and, in gene greater effort to produce recreational trips.

Projections of growth in recreational trip supply presented in this chapter to reflect what may happen future years if recent trends in recreational opportu ties continue to the year 2040. Supply projections selected activities are compared. Recent trends in t amount and availabilities of land, water, and snow a ice resources were reviewed in chapter I and brie reiterated in an earlier section of this chapter.

Estimates of future trends are shown in table 15 a represent an extension into the future of the rece resource trends described in chapter I. Thus, if no mark or policy changes occur, the extended trends in table reflect the most likely future for availabilities of lan water, and snow and ice resources for recreation. On th

Projections of future recreation supply were made with the assumption that recent trends would continue.

Table 15.—Estimated future trends in land, water, and snow and ice resources and environments if recent trends (1970–1987) in amounts of resources available for outdoor recreation were to continue.

Resources and environments	Projected percentage change from 1987				
	2000	2010	2020	2030	2040
Land					
Wilderness and other extensive roadless areas	−9	−15	−21	−26	−31
Undeveloped areas near roads	−12	−20	−28	−35	−41
Partially developed, roaded areas	−9	−15	−21	−26	−31
Intensively developed sites	8	15	22	29	37
Water					
Wild and remote lakes and streams	3	6	8	9	10
Lakes and streams near roads	−3	−4	−6	−8	−10
Lake and stream sites adjoined by roads	8	15	22	29	37
Intensively developed water sites	12	23	34	47	61
Snow and ice					
Wilderness and other roadless areas	−9	−15	−21	−26	−31
Undeveloped areas near roads	−12	−20	−28	−35	−41
Partially developed, roaded areas	−9	−15	−21	−26	−31
Intensively developed winter sports sites	17	28	36	43	49

Table 16.—Current supply of recreational trips away from home and indices of future growth to 2040 if recent resource availability trends continue.

Resource category and activity	Trips in 1987 (millions)	Percentage of 1987 supply				
		2000	2010	2020	2030	2040
Land						
Wildlife observation and photography	69.5	107	113	120	126	130
Camping in primitive campgrounds	38.1	108	115	122	130	134
Backpacking	26.0	124	144	165	185	198
Nature study	70.8	99	101	103	107	108
Horseback riding	63.2	114	125	135	144	149
Day hiking	91.2	123	144	168	198	229
Photography	42.0	115	128	141	154	163
Visiting prehistoric sites	16.7	127	148	173	203	236
Collecting berries, etc.	19.0	110	120	132	149	169
Collecting firewood	30.3	109	118	130	144	161
Walking for pleasure	266.5	116	132	148	168	183
Running/jogging	83.7	131	160	192	229	260
Bicycle riding	114.6	124	146	170	197	218
Off-road driving	80.2	104	108	112	118	121
Visiting museums and information centers	9.7	118	134	152	172	187
Attending special events	73.7	115	129	144	161	175
Visiting historic sites	73.1	117	133	152	178	204
Driving for pleasure	421.6	110	120	129	139	145
Family gatherings	74.4	121	139	160	182	202
Sightseeing	292.7	114	128	144	164	185
Picnicking	262.0	110	120	131	145	156
Camping in developed campgrounds	60.6	120	138	158	178	195
Water						
Canoeing/kayaking	39.8	113	126	138	153	163
Stream/lake/ocean swimming	238.8	108	118	128	140	152
Rafting/tubing	8.9	123	151	182	229	267
Rowing/paddling/other boating	61.8	110	120	130	142	150
Motor boating	219.5	107	114	122	131	138
Water skiing	107.5	112	122	132	144	152
Pool swimming	221.0	135	166	200	237	267
Snow and ice						
Cross-country skiing	9.7	125	136	142	141	126
Downhill skiing	64.3	159	208	261	317	359

basis, the projections in table 16 predict the most likely future supplies of recreational trip opportunities.

Expected Future Land-Based Recreation Supply

In general, across the land activities listed in table 16, continuation of recent trends in making resources available for public recreation will lead to expansion of recreational trip supply as households find ways to more effectively utilize increasingly scarce opportunities. This growth is projected at about 15% overall to the year 2000. The supply of land activities projected to grow most rapidly includes running/jogging (31%), visiting prehistoric sites (27%), bicycle riding and backpacking (24%), day hiking (23%), and family gatherings and developed camping (21% and 20%, respectively). In total, projected growth in trip supply among these seven activities is expected to reach just over 140 million per year by the year 2000.

Among the land recreation environments in fig. 39, supply of developed-site trip opportunities is expected to grow most rapidly, 8% by 2000. This represents continuation of recent trends and, if continued, is expected to result in 11% growth of recreational trip supply. Supply of both motorized and nonmotorized recreational trips in roaded, partially developed lands and in extensive roadless lands is projected to grow 9% to 10% by 2000. This growth is projected even though the land area in these environments is expected to decrease 9% to 12% by 2000. This growth of trip supply in the face of decreasing resource availabilities reflects a large, unused capacity, especially on public lands. Households and individuals will have the capabilities, apparently, to produce more trips even though the costs of doing so are likely to be greater.

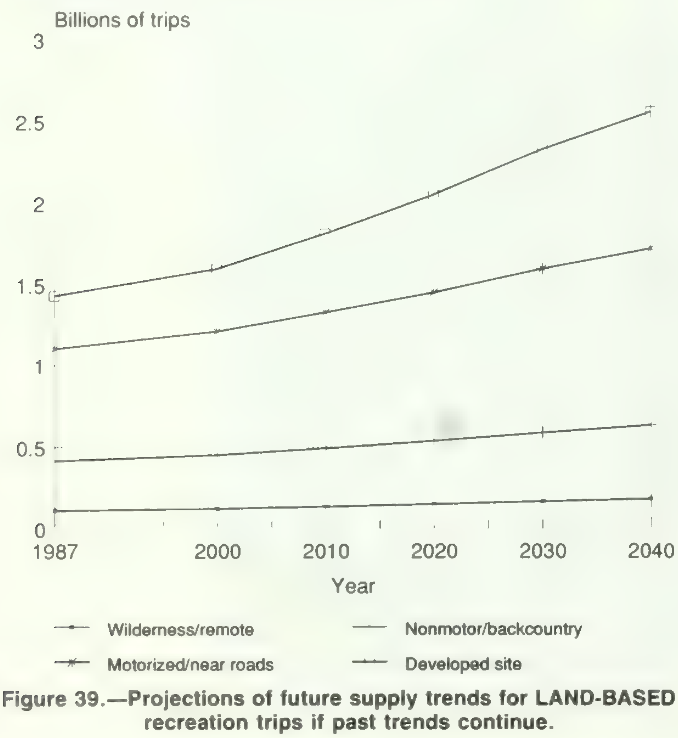


Figure 39.—Projections of future supply trends for LAND-BASED recreation trips if past trends continue.

For the most part, the relative growth rates among land activities should remain about the same in future years. The one dominant theme among the fastest growing activities is their dependence upon access, trails, and developed site resources. Substantial growth of these resources could lead to substantial increases in recreational trip supply in future years.

The slowest growing activities mostly depend upon roaded and partially developed rural lands. Continuation of the recent downward trends in access to these resources will result in very slow rises in recreation supply as households must overcome the shrinkage in site and access by using different means and technology to produce their recreational trips and experiences.

Expected Future Water and Snow/Ice-Based Recreation Supply

For the most part, water recreational trip supply will grow moderately with continuation of recent resource availability trends. The exceptions are rafting/tubing (24% by 2000) and pool swimming (35%), which are projected to grow rapidly. Motorized water recreation supply will grow slowly if recent trends continue. Access, technology, and services associated with rafting and tubing types of activities (especially outfitter and guide services) have risen rapidly in recent years. So, too, has the number of swimming pools. Continuation of these trends is projected to result in rapid growth of the supplies of these opportunities. In fact, pool swimming supply is projected to increase to levels beyond that of stream, lake, and ocean swimming supply by 2020. Continuation of the moderate expansion of resources suitable for motorized water recreation, a rate that is somewhat below that of population growth, is projected to lead to proportionate rises in supply of motorized water trip opportunities as reservoirs and lakes continue to be crowded at peak times (fig. 40).

The decrease of undeveloped and roaded rural lands in areas with good winter snowfall is projected to cause slow growth for supply of cross-county skiing and similar dispersed activities. Actually, the supply of dispersed winter recreational trip opportunities should rise moderately through 2010, and then a continued loss of access and expected conversions to incompatible other uses of private and public lands may cause decreases through 2040. If recent trends continue, downhill skiing supply could continue to rise rapidly as both new sites and new capacities are added. Such development pressures from downhill skiing could actually contribute to some loss of of cross-country opportunity. While continuation of recent past trends is an assumption of this Assessment across all types of recreational environments, ski industry projections forecast a slowing of the rapid growth which dominated in the 1960's and 1970's.

Different forms of recreation supply will grow in the future at very different rates if recent resource availability trends are continued (table 16, figs. 39 and 40). Following these trends into the future sometimes matches well with what the public will likely prefer. Where this

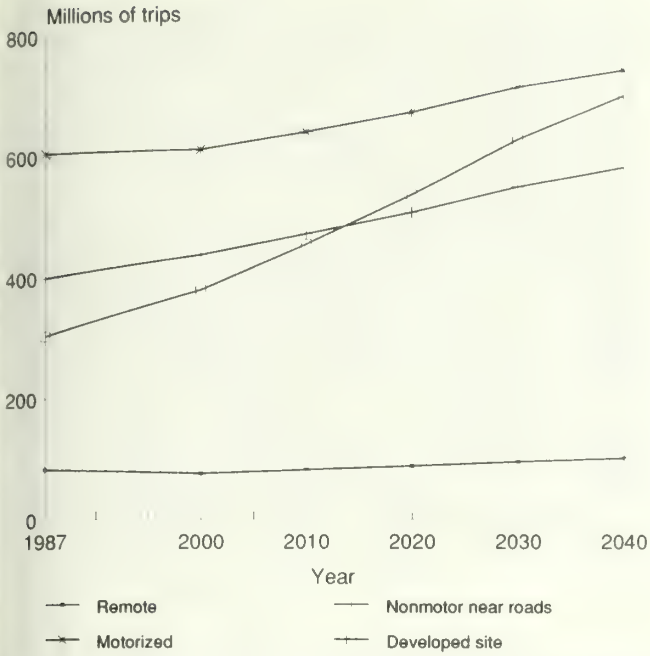


Figure 40.—Projections of future supply trends for WATER-BASED recreation trips if past trends continue.

occurs, few if any shortages should occur. But for some activities, recent supply trends may not match public demand for recreation opportunities, and a different course into the future may need to be considered. These are among the topics covered in the next chapter.

Wilderness

The extent of the National Wilderness Preservation System, NWPS, is described in chapter I. The size of the System and the availability of wilderness is likely to expand considerably within the next decade. However, the characteristics of potential wilderness are greatly influenced by the language of the Wilderness Act. The way in which current wilderness areas are managed also significantly affects availability.

Current Availability

The opportunity for public use was one of the overriding concerns of the Wilderness Act. With few exceptions, the entirety of the System is accessible for appropriate public uses. Geographic location among the nation's population is not a criterion in the designation of wilderness areas. Because wilderness is an administrative "overlay" on federal lands, its location is not random. It will always be tied to existing federal land ownership patterns. In an ideal sense, wilderness is equally available to all Americans. But, in a practical sense, its geographic distribution makes wilderness more accessible to certain populations.

On a regional or state level, the location of wilderness will probably always be unevenly distributed across the nation in terms of population. The majority of federal lands are located in the 11 western states and Alaska. While these states account for only about 20% of the nation's population, they hold more than 95% of the wilderness areas. Alaska alone has nearly two-thirds of the total national wilderness acreage, but less than 1% of the national population. Residents of states east of the Rocky Mountains, therefore, must often either travel greater distances and spend more money to get to a wilderness area or share it with a greater number of people (on a per capita acreage basis).

Representativeness of ecosystem type is also not a formal criterion for the designation of wilderness. The ecosystems which are available for use in the NWPS are again limited to those in federal ownership. Due to the contribution of Alaska, nearly one-half of the available wilderness areas have tundra or subarctic ecosystems. The majority of wilderness areas in the contiguous states are located in forested, mountainous areas. Particularly underrepresented in the System is wilderness prairie.

Properly managing wilderness is as important as including more acreage in the NWPS. Designation alone cannot guarantee wilderness opportunities because wilderness, to a large degree, depends upon human perception of its qualities. Impacts from excessive or improper recreational use can degrade wilderness character. Similarly, the influences of acid precipitation, global warming, and aircraft overflights, among other possibilities, may also adversely impact wilderness. Therefore, although wilderness in name, lands so designated could no longer effectively offer wilderness opportunities or experiences. In effect, extraneous factors could reduce the supply of wilderness.

Wilderness by law serves multiple purposes which may conflict with each other. As more becomes known about the nonrecreational values of wilderness, these conflicts may become more apparent. The available opportunity for any given use may need to be adjusted through management. As new wilderness areas are designated, criteria regarding acceptable levels of change should be adopted.

Recent Trends in Supply

Growth of the NWPS has not followed easily identifiable patterns and, thus, does not lend itself to mathematical trend analysis. Rather, it has been the field of politics which better explains and predicts trends.

Since its inception in 1964, the System has grown tenfold to nearly 89 million acres. But this growth has not occurred uniformly every year, and several significant events have shaped the current System and its growth. Following the Wilderness Act in 1964, the Eastern Wilderness Act (1974) and Endangered American Wilderness Act (1978) both served to change operational definitions of what could be considered potential wilderness. The Federal Land Management Policy Act (1976) added a fourth agency (the Bureau of Land Management) charged with wilderness preservation and management. The Alaska National Interest Lands Act (1980) more than doubled the size of the NWPS with wholesale realloca-

tion of federal lands among agencies. In these acts, the supply of wilderness was increased as a result of a long political effort reflecting the will (or demand) of the nation.

New additions to the System have often been delayed until key resource issues were resolved, especially water rights. The future size of the System, therefore, also depends upon the courts to interpret existing legislation. Perhaps reflecting this trend, legislation creating new wilderness areas over the past 10 years has begun to be more specific regarding the designation purposes and to state exceptions or additions to Wilderness Act provisions. Again, the consequence is that differing amounts of the System may be available for different uses, complicating the description of supply.

Projected Supply

Despite pending resource issues, the NWPS will most likely continue to grow over the coming decade. Observers note that competing commercial interests such as timber, mining, and grazing have begun to find potential wilderness areas less attractive in the present economy. Noted, too, is the fact that Congress has generally exceeded the recommended acreage when designating new areas (McCloskey 1989). Estimates of the ultimate size of the System have been put as high as 350 million acres (Flamm 1989).

Regardless of designation purpose, legal interpretation, and conflicting resource issues, most large additions to the NWPS are likely to occur in Alaska and the West. Considerable acreage in Alaska managed by the National Park Service and the Fish and Wildlife Service may eventually enter the System. The BLM estimates that up to 15 million acres throughout the western states could enter the System over the next several years. Many of these areas would be designated more for their nonrecreational values than for their recreation potential.

CHAPTER IV: HOW MAXIMUM PREFERRED DEMAND COMPARES TO AVAILABILITY OF RECREATION AND WILDERNESS OPPORTUNITIES

Introduction

In the first part of this chapter, maximum preferred uture demand for outdoor recreational trips away from iome, as presented in chapter II, is summarized. Next, uture supply of recreational trip opportunities, given ı continuation of recent trends in the provision of recreaional and wilderness facilities and resources, as preented in chapter III, is reviewed. How maximum referred demand compares to likely future supplies of ecreational trip opportunities is then discussed. Following this discussion, implications of alternative future ates of change in the availability of recreational facilities and resources are considered. General observations oncerning the supply and demand of outdoor recreaion and wilderness in the United States are then proided in the final sections.

The Demand Outlook: Outdoor Recreation Opportunities Preferred by Americans

'rends and Influences in Demand

People still enjoy traditional outdoor recreation activiies, but the growth rate of demand for these activities ıas slowed since the 1950's and 1960's. "Baby boomrs," those Americans born between 1946 and 1964, are rowing older. As this large segment of the American opulation ages, recreation preferences change. Age ften limits the ability of some people to participate in ome activities.

Other important dimensions to demographic changes, in addition to aging, influence demand growth. The American population is growing at a much slower rate than in the past. Dual-income households are expected to become increasingly common so discretionary income should increase dramatically for much of the population. With more members working, however, families may realize less leisure time and encounter more difficulty in taking advantage of recreational opportunities. Americans are living longer and enjoying generally higher levels of health and physical fitness. All of these, and perhaps other factors, contribute to shifting preferences in outdoor recreation demand.

Maximum Preferred Demand

Method.—For this Assessment, projections of future demand for outdoor recreation are expressed as maximum preferred demand, which is defined as the number of outdoor recreational trips away from home that Americans would take if just enough opportunities exist to satisfy those preferred number of trips. This definition assumes no shortages of opportunities would occur and that the cost of a trip would remain at today's level. In 1987, Americans took an estimated 4.5 billion recreational trips away from home, mostly to rural forest, range, and water areas, according to the research provided by this Assessment using the Public Area Recreation Visitors Study. From this base of current recreation demand, projections of the public's maximum preferred demand for recreational trips were developed for each

Because baby boomers are entering middle age, recreational preferences are expected to shift.

decade through 2040. (Selected recreational activities which typically occur across the forest and range recreational environments are shown in figure 1.) Projections were based on assumptions about five factors which significantly influence recreation demand. These assumptions were: (1) the cost of taking trips in the future will remain the same as it is now; (2) the percentage of the population earning more than $30,000 a year will rise; (3) the proportion of young adults (persons 18 to 32 years old) in the population will fall; (4) overall, the population will grow but at a decreasing rate; and (5) the availability of recreational opportunities will be adequate in the future. Projections are measured from this Assessment's benchmark year, 1987, as a percentage change in number of trips. Projections of maximum preferred demand are discussed in more detail in chapter II.

Result.—For the growing number of older Americans and those baby boomers who now have families at home, simple recreational activities such as picnicking, pleasure driving, sightseeing, and day hiking should continue to be popular even though rates of increase should be modest. These activities are easily accessible, require only moderate amounts of time, are inexpensive, and are easy to organize. Maximum preferred demand for them will increase steadily. Seemingly contradictory to this trend, maximum preferred demand for more expensive, time consuming, and adventuresome recreational activities such as rafting/tubing, canoeing, kayaking, downhill skiing, cross-country skiing, and backpacking should increase considerably. This predicted trend may diminish as baby boomers age, but it may rise again toward the end of the 50-year period considered here as boomers' children begin to pursue the recreation interests they learned from their parents. The simultaneous growth of both passive and adventurous activities may not be a contradiction but a demonstration of preference for variety to match the increasing varied lifestyles, cultural backgrounds, and personal abilities.

Continued interest in health and physical fitness may contribute to increased demand for exercise-oriented activities that are broadly available and easily engaged in close to home. Maximum preferred demand for bicycling, swimming, walking, running, and jogging shows a steady increase in the future. Slight increases in maximum preferred demand will occur for primitive camping, driving vehicles or motorcycles off-road, nature study, collecting forest products (such as firewood, berries, seashells, and mushrooms), wildlife observation and photography, motor boating, and water skiing.

The increasing number of low-income families, particularly urban-bound minorities, has the potential to change the complexion of outdoor recreation demand. Because of limited incomes and lack of exposure to outdoor environments, minorities often participate in outdoor recreation substantially differently than do affluent Americans. For example, a popular recreational activity among some low-income ethnic groups is family gatherings, and maximum preferred demand for family gatherings is projected to increase at a relatively high rate in the future. By and large, however, low-income urban people represent an outdoor recreation constituency which, in many ways, has yet to be effectively recognized by most resource management agencies. This group can potentially become more active in many forms of outdoor recreation if the availability of appropriate opportunities increases or incomes, knowledge of, and access to the out-of-doors increase.

The Supply Outlook: Continuing Past Resource Availability Trends

As explained in more detail in chapters I and III, the effectiveness of the types, qualities, and quantities of outdoor recreational facilities and resources vary considerably across the United States. Because the West has extensive public land and a relatively small population, effective land-based recreational opportunities are generally 5 to 15 times greater than in the East. To even out the regional availability of land-based recreational opportunities per person, a large population shift from East to West would have to occur, or availability of land-based recreational opportunities in the East would have to increase dramatically. Some recreational opportunities, such as remote wilderness backpacking, however, will likely remain relatively scarce in the East.

The uneven distribution of opportunities is not as extreme for water recreation. Effective opportunities for some types of water-based recreation are comparable between East and West. A major difference is less effective coldwater and white water opportunity in the East.

Another important difference between East and West is the impact of crowding. Congestion generally reduces the satisfaction people obtain from an outdoor recreational experience (Cicchetti and Smith 1976, McConnell 1977, Walsh et al. 1983). Potential impacts of crowding are reflected in the measures of effective recreational opportunity presented in chapter III. In the West, many large population centers are close to vast tracts of largely undeveloped public lands, usually managed by the Forest Service or the Bureau of Land Management. Denver residents, for example, are within 1 hour's drive of the Roosevelt, Arapaho, and Pike National Forests. Residents of Los Angeles, Seattle, Portland, Salt Lake City, and Phoenix all have similar opportunities just outside their city limits.

Thus, in the West, effective recreational opportunities are relatively large for many activities. The implication is that each person can access many recreational facilities or resources within a reasonable driving distance if he or she so desires. The extent of crowding or congestion is less in the West. In the East, very few relatively undeveloped land and water areas are located within 1 hour's drive of a population center. Effective recreational opportunities dependent on these undisturbed settings are, therefore, relatively small. This means that the likelihood of crowding or congestion is greater than in the West since each person has access to fewer recreational spaces, facilities, or resources within a reasonable driving distance. The lack of recreational opportunities close to large population centers in the East is most severe for remote backcountry, wilderness, and other extensive, roadless environments.

Continued interest in health and physical fitness activities which are available close to home shows a steady increase into the future.

Inner city residents could become more active in outdoor recreation if appropriate opportunities are made available, or their income, knowledge of, and access to the out-of-doors increase.

The use of private lands for outdoor recreation potentially could ease the uneven geographic distribution of recreational opportunities. In addition to the 283 million acres of private lands open to the public or leased for recreation in 1987, 556 million acres of private lands are available to acquaintances of individual owners. Much of these 839 million acres are located in the East. Recent trends, however, indicate that the number of acres open to the public without a lease is steadily decreasing. Compared to 10 years ago, almost 10% more private, nonindustrial land is now closed to the public, according to research conducted for this Assessment with the National Private Landowner Survey data. Additionally, more than one-third of the private industrial lands open to the public in 1960 are now closed. Unless trends are reversed, private lands may not have a substantial impact on the future availability of effective recreational opportunities in the East.

Often, people cannot take all of the trips they would prefer. The type and number of recreational trips which people can take may be limited, in part, by available recreational facilities or resources. In chapter III, the supply of opportunities for recreational trips was projected under the assumption that recent resource availability trends would continue into the future.

Continued trends in the availability of different land, water, and snow and ice facilities and resources are described in table 15. Gains and losses largely reflect the recategorizing of facilities and resources as a result of building roads and the development that typically follows improved access. For land resources, only the intensively developed site category shows an increase in available facilities and resources. Wilderness and roadless areas, undeveloped areas near roads, and partially developed, roaded areas all show sharp declines.

With respect to water resources, wild and remote lakes and streams, lake and stream sites adjoining roads, and intensively developed water sites all show increases in available facilities and resources. Lakes and streams near roads show a decline. As development progresses, some waters will have to be reclassified. This and additional closures of private land will alter the accessibility picture. For snow and ice, only intensively developed winter sports sites show increases in available facilities and resources while wilderness and roadless areas, undeveloped areas near roads, and partially developed roaded areas show decreases.

Projected Future Supply of Recreational Trips

The supply of recreational opportunities can be measured in terms of recreational trips. This measuring unit reflects the availability of facilities and resources plus the actions of recreationists who use them. Recreational trips cannot be purchased at the local convenience store like a loaf of bread. As described in chapter III, if a person desires to enjoy a recreational trip, he or she must use their own time, travel, experience, knowledge, and equipment, along with available recreational facilities and resources, to "produce" or take a recreational trip.

The supply of opportunities for recreational trips is, therefore, determined by a two-step process. First, public or private agencies, groups, or individuals make recreational facilities and resources available to the public. Second, households make given resources and facilities destinations for intended use. Projections of the future supply of opportunities for recreational trips consider both of these supply steps.

Future expected supply of trip opportunities was determined by calculating the total number of trips that the public will take if recent trends in the availability of recreational facilities and resources continue. The calculations also consider those factors which influence the public's recreation decisions. The factors affect household production and, thus, are used to predict the expected supply of trip opportunities. Thus, the expected future supply of trip opportunities represents the expected number of trips that the people will most likely produce given constraints of time, income, location, access, technology, personal skill, and amount of facilities.

If recent trends continue, the availability of resources should stimulate an increase of trip opportunities for activities such as biking, day hiking, walking, running and jogging. More passive recreational activities that show a relatively high increase in expected supply of trip opportunities include developed camping, sightseeing, visiting museums, and visiting historic and prehistoric sites. Expected trip opportunity supply will also increase at a relatively high rate for some of the more active and adventuresome activities including rafting and downhill skiing.

Expected trip opportunity supply should increase at a moderate rate for picnicking, horseback riding, river and lake swimming, canoeing and kayaking, and cross-country skiing. Expected trip opportunity supply for specialized land-based activities, including primitive camping, nature study, wildlife observation, and off-road driving will increase at a relatively low growth rate. General activities that show a relatively low increase in expected trip opportunity supply include motorboating and driving for pleasure.

Comparison of Preferred Demand and Expected Supply

Projections of maximum preferred demand indicate the number of recreational trips Americans would prefer to take in the future if the availability of recreational facilities and resources or increased trip costs did not limit their opportunities. Projections of expected supply indicate opportunities for recreational trips assuming that recent trends in the availability of recreational facilities and resources continue. That is, expected supply represents recreational trip opportunities if either planned or market-driven deviations from past trends do not occur.

Both supply and demand are measured by recreational trips. Thus, by comparing projections of maximum preferred demand to projections of expected supply of trip opportunities, differences affecting discrete activities can be identified and measured using the same units.

The 1987 base year for this Assessment represents an equilibrium between demand and supply[7] measured in number of trips away from home. Projections of maximum preferred demand and expected supply for activities that occur on forest and range are indexed to this 1987 base as shown in table 17. The percentage by which preferred demand exceeds expected supply is also shown. The methodology upon which this demand-supply comparison is based is presented in detail in Cordell and Bergstrom (1989).

The severity of a demand-supply gap may not be totally revealed by the percentage difference. Even a small percentage difference can have major social, economic, and environmental consequences if it represents a relatively large number of trips. Thus, demand-supply

[7]In the base year, demand is assumed to equal supply.

Table 17.—Projected gap between maximum preferred demand and expected supply of outdoor recreational trips away from home, measured as percentage difference by decade to 2040.

Resource category and activity	Trips in 1987 (millions)	Percentage of 1987 trips				
		2000 D/S/G[1]	2010 D/S/G	2020 D/S/G	2030 D/S/G	2040 D/S/G
Land						
Wildlife observation and photography	69.5	116/107/ 9	131/113/18	146/120/26	162/120/26	174/130/44
Camping in primitive campgrounds	38.1	114/108/ 6	127/115/ 8	140/122/18	154/130/24	164/134/30
Backpacking	26.0	134/124/10	164/144/20	196/165/31	230/185/45	255/198/57
Nature study	70.8	105/ 99/ 6	113/101/12	120/103/17	131/107/24	138/108/30
Horseback riding	63.2	123/114/ 9	141/125/10	160/135/25	177/144/33	190/149/41
Day hiking	91.2	131/123/ 8	161/144/17	198/168/30	244/198/46	293/229/64
Photography	42.0	123/115/ 8	143/128/15	165/141/24	188/154/34	205/163/44
Visiting prehistoric sites	16.7	133/127/ 6	160/148/12	192/173/19	233/203/30	278/236/42
Collecting berries, seashells, mushrooms, etc.	19.0	113/110/ 3	126/120/ 6	143/132/11	166/149/17	192/169/23
Collecting firewood	30.3	112/109/ 3	124/118/ 6	138/130/ 8	157/144/13	178/161/17
Walking for pleasure	266.5	116/116/ 0	131/132/ 0	146/148/ 0	164/168/ 0	177/183/ 0
Running/jogging	83.7	133/131/ 2	163/160/ 3	197/192/ 5	234/229/ 5	262/260/ 2
Bicycle riding	114.6	125/124/ 1	148/146/ 2	173/170/ 3	202/197/ 5	222/218/ 4
Driving off road	80.2	105/104/ 1	111/108/ 3	118/112/ 6	125/118/ 7	130/121/ 9
Visiting museums or infornmation centers	9.7	118/118/ 0	136/134/ 2	153/152/ 1	174/172/ 2	188/187/ 1
Attending special events	73.7	114/115/ 0	127/129/ 0	141/144/ 0	157/161/ 0	168/175/ 0
Visiting historic sites	73.1	122/117/ 5	143/133/10	169/152/17	203/178/25	241/204/37
Driving for pleasure	421.6	115/110/ 5	128/120/ 8	142/129/13	157/139/18	167/145/22
Family gatherings	74.4	119/121/ 0	135/139/ 0	152/160/ 0	170/182/ 0	182/202/ 0
Sightseeing	292.7	118/114/ 4	136/128/ 8	156/144/12	183/164/19	212/185/27
Picnicking	262.0	108/110/ 0	117/120/ 0	126/131/ 0	136/145/ 0	144/156/ 0
Camping in developed campgrounds	60.6	120/120/ 0	137/138/ 0	155/158/ 0	173/178/ 0	186/195/ 0
Water						
Canoeing/kayaking	39.9	113/113/ 0	126/126/ 0	140/138/ 2	157/153/ 4	169/163/ 6
Stream/lake/ocean swimming	238.8	105/108/ 0	110/118/ 0	117/128/ 0	124/140/ 0	129/152/ 0
Rafting/tubing	8.9	111/123/ 0	136/151/ 0	164/182/ 0	215/229/ 0	255/267/ 0
Rowing/paddling/other boating	61.8	112/110/ 2	124/120/ 4	136/130/ 6	150/142/ 8	159/142/ 9
Motorboating	219.5	106/107/ 0	111/114/ 0	117/122/ 0	123/131/ 0	127/138/ 0
Water skiing	107.5	111/112/ 0	121/122/ 0	131/132/ 0	141/144/ 0	148/152/ 0
Outdoor pool swimming	221.0	137/135/ 2	169/166/ 3	205/200/ 5	242/237/ 5	269/267/ 2
Snow and ice						
Cross-country skiing	9.7	147/125/22	177/136/41	199/142/57	212/141/71	195/126/69
Downhill skiing	64.3	153/159/ 0	197/208/ 0	247/261/ 0	298/317/ 0	333/359/ 0

[1] *D is the maximum preferred demand; S is the expected supply; and G is the percentage difference (gap) between demand and supply. D, S, and G are all expressed as percentages of the 1987 base number of trips. In the projection base year of 1987, demand is assumed to equal supply with zero gap, that is, demand and supply are in equilibrium.*

gaps are presented also in terms of absolute numbers of trips in table 18.[8]

Zeroes in tables 17 and 18 indicate that no gaps are predicted. The implication of a "no gap" situation is that past trends extended into the future will increase recreational facilities and resources at rates sufficient to permit Americans to take as many recreational trips as they prefer at the 1987 level of trip costs. Projected gaps are graphically illustrated for selected activities in figures 41 through 46.

Implications of Alternative Rates of Recreational Opportunity Growth

Continuation of Recent Trends

Even without study, a person could accurately surmise that the future promises a mixture of increasing and decreasing recreational opportunities. But, generalizations cannot so accurately predict which activities will gain and which will lose opportunities. By considering the extension of recent trends, we can identify specific opportunity shifts. For example, continuing the trends indicates losses of remote, roadless and roaded forest and of farm and range areas available for recreation. Developed recreation sites will continue to increase. These increases or decreases will affect the expected future supply of outdoor recreation opportunities differently. Where the predicted effects are significant, the shortages between demand and supply have implications for future resource management and research.

Shortages are predicted for the three most basic categories of resources. As a possible implication for policy, the most serious is the expected shortfall in opportunities for warm-season trips to both roadless and roaded undeveloped areas (fig. 47). Shortages of land-based recreational opportunities are predicted to occur most dramatically for roaded, partially developed opportunities. These places provide opportunities for activi-

[8] *While data in tables 17 and 18 should be read with caution (it is perhaps unrealistic, for example, to assume that the pace of development of down-hill ski facilities will continue long into the future), this analysis does help identify potential supply shortfalls warranting attention.*

Table 18.—Projected gaps between preferred demand and expected supply of outdoor recreational trips away from home.

Resource category and activity	Difference between demand and supply in millions of trips (and percentage)				
	2000	2010	2020	2030	2040
Land					
Wildlife observation and photography	6.3 (9)	12.5(18)	18.1(26)	25.0(36)	30.6(44)
Camping in primitive campgrounds	2.3 (6)	3.0 (8)	6.9(18)	9.1(24)	11.4(30)
Backpacking	2.6(10)	5.2(20)	8.1(31)	11.7(45)	14.8(57)
Nature study	4.2 (6)	8.5(12)	12.0(17)	17.0(24)	21.2(30)
Horseback riding	5.7 (9)	14.6(16)	22.8(25)	30.1(33)	37.4(41)
Day hiking	7.3 (8)	15.5(17)	27.4(30)	42.0(46)	58.4(64)
Photography	3.4 (8)	6.3(15)	10.1(24)	14.3(34)	18.5(44)
Visiting prehistoric sites	1.0 (6)	2.0(12)	3.2(19)	5.0(30)	7.0(42)
Collecting berries, seashells, mushrooms, etc.	0.6 (3)	1.1 (6)	2.1(11)	3.2(17)	4.4(23)
Collecting firewood	0.9 (3)	1.8 (6)	2.4 (8)	3.9(13)	5.2(17)
Walking for pleasure	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Running/jogging	1.7 (2)	2.5 (3)	4.2 (5)	4.2 (5)	1.7 (2)
Bicycle riding	1.1 (1)	2.3 (2)	3.4 (3)	5.7 (5)	4.6 (4)
Driving off-road	0.8 (1)	2.4 (3)	4.8 (6)	5.6 (7)	7.2 (9)
Visiting museums and information centers	0 (0)	0.2 (2)	0.1 (1)	0.2 (2)	0.1 (1)
Attending special events	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Visiting historic sites	3.6 (5)	7.3(10)	12.4(17)	18.3(25)	27.0(37)
Driving for pleasure	21.1 (5)	33.7 (8)	54.8(13)	75.9(18)	92.8(22)
Family gatherings	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Sightseeing	11.7 (4)	23.4 (8)	35.1(12)	55.6(19)	79.0(27)
Picnicking	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Camping in developed campgrounds	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Water					
Canoeing/kayaking	0 (0)	0 (0)	0.8 (2)	1.6 (4)	2.4 (6)
Stream/lake/ocean swimming	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Rafting/tubing	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Rowing/paddling/other boating	1.2 (2)	2.5 (4)	3.7 (6)	4.9 (8)	5.6 (9)
Motorboating	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Water skiing	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Outdoor pool swimming	4.4 (2)	6.6 (3)	11.1 (5)	11.1 (5)	4.4 (2)
Snow And Ice					
Cross-country skiing	2.1(22)	4.0(41)	5.5(57)	6.9(71)	6.7(69)
Downhill skiing	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

ties such as day hiking, nature study, horseback riding, and sightseeing. These are also the places where most types of hunting and most other general forms of land-based dispersed recreation occur. In particular, private forest and range lands near populated areas, as well as "close-in" public lands, represent both a reason for possible future shortages and an opportunity to meet demand growth. Providing adequate future opportunities for wildlife observation, day hiking, photography, driving for pleasure, sightseeing, and similar activities would most directly address predicted national supply shortages for about 75% of outdoor recreation.

The availability of developed recreation sites responds more readily to market signals than other types of long-term opportunities. Thus, planned long-run rate increases may be unnecessary; the market may attract sufficient investments to increase the number of sites.

Demand for water and snow and ice recreation typically has grown at faster rates than land-based recreation and has tended to receive much more policy and planning attention. But the magnitude of projected trip opportunity gaps for land-based recreation is much larger than water or snow and ice opportunity gaps. For example, even though the gap for developed land-based recreation is small relative to that for dispersed land recreation, the projected shortage of developed land trip opportunities still is approximately four times that projected for water and snow and ice opportunities combined.

If recent trends in availability of facilities and resources continue, a relatively small shortage should influence water recreational opportunities. Mostly, such shortages will affect opportunities for nonmotorized lake and river activities and for outdoor pool swimming. Snow- and ice-based recreational opportunity shortages should be greatest among dispersed activities such as cross-country skiing.

One major implication of these findings seems to be that prompt attention is needed to research and develop incentives regarding public access to private lands. Continuation of closure and leasing trends could have serious negative consequences. The effects of these trends are certainly being felt now. Another implication is that more access and information about available public land near urban centers are needed. The most visible need does not seem to be for development of public lands but for access, trails, and information.

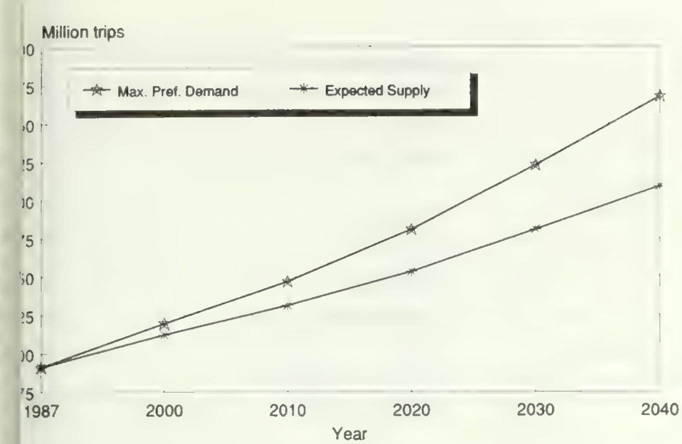


Figure 41.—Projected gap between maximum preferred demand and expected supply for day hiking.

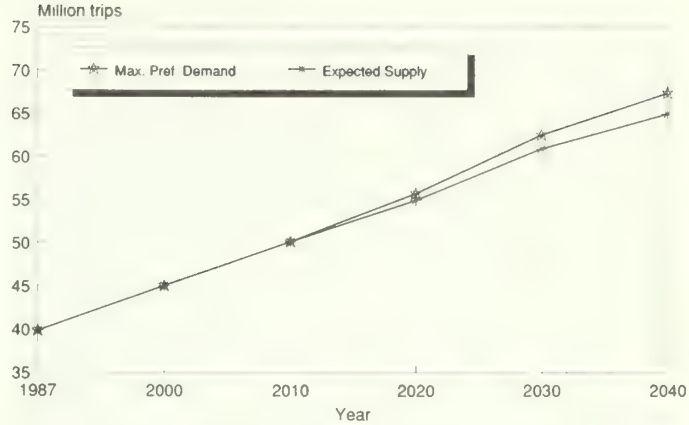


Figure 44.—Projected gap between maximum preferred demand and expected supply for canoeing and kayaking.

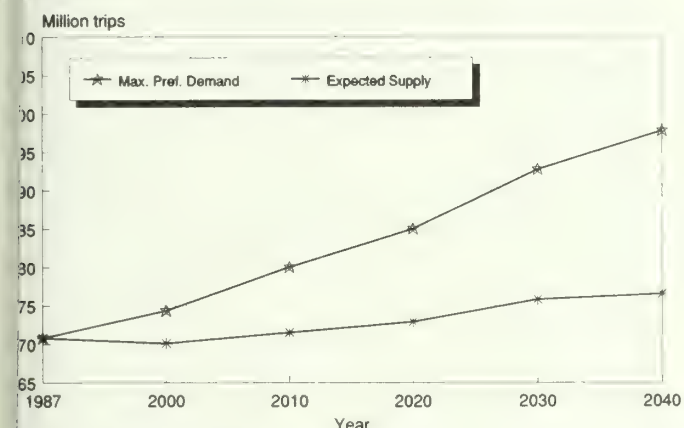


Figure 42.—Projected gap between maximum preferred demand and expected supply for nature study.

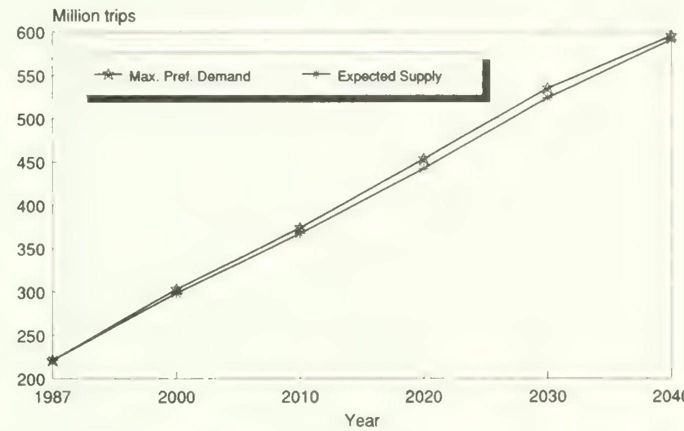


Figure 45.—Projected gap between maximum preferred demand and expected supply for outdoor pool swimming.

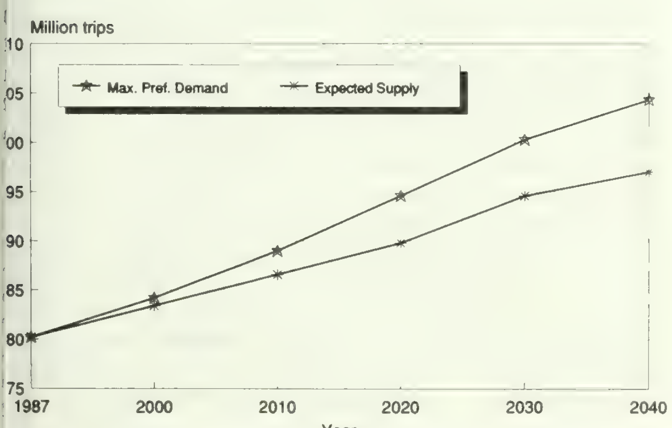


Figure 43.—Projected gap between maximum preferred demand and expected supply for off-road driving.

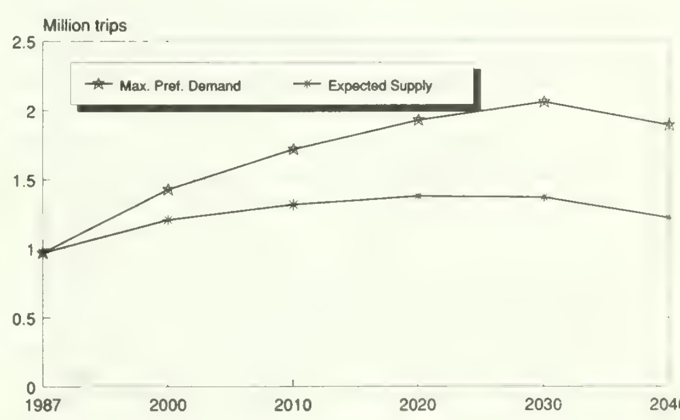


Figure 46.—Projected gap between maximum preferred demand and expected supply for cross-country skiing.

Assumption of No Growth in Available Federal Facilities and Resources

The gaps between preferred demand and expected supply of trip opportunities discussed in the preceding section are conditional upon federal recreational facilities and resources increasing or decreasing in the future at the same rates as recent trends. A different gap situation would occur if the availability of all facilities and resources, except federal, were to change in the future at the same rates as recent trends. With availability of federal facilities and resources held at current levels, the gap between preferred demand and expected supply would widen considerably for primitive camping. Gaps would widen slightly for collecting berries, seashells, and mushrooms, collecting firewood, driving off-road, driving for pleasure, sightseeing, and visiting historic and prehistoric sites. Gaps would also widen slightly for canoeing or kayaking, and rafting after the year 2020. Downhill skiing would have a relatively large gap because such a large percentage of the opportunity has been developed on national forests.

For many other activities, however, gaps would be reduced if federal facilities and resources were to be held constant, since some recent trends actually show declines in resources and facilities. Holding facilities and resources at current levels implies a gain compared to continuation of recent trends. Holding resources and facilities at current levels also implies increased investments beyond those currently planned. For example, the gap between preferred demand and expected supply for cross-country skiing would be eliminated by maintaining existing levels of opportunities because there would be no competing uses, road closures, or development to decrease the cross-country skiing opportunity base. Gaps would also move toward elimination by a moderate amount for the land-based activities of backpacking, and wildlife observation and photography. Gaps would begin to close slightly for day hiking, horseback riding, and nature study.

Resource Availability Growth Rates Needed to Satisfy Preferred Demand

Of potential interest in planning future resource management and policy are the growth rates for recreational facilities and resources that would be needed to satisfy projected future preferred demand. A high rate[9] of recreational facility and resource growth, about 1% per year, would be needed to satisfy maximum preferred demand for day hiking, bicycling, running and jogging, driving off-road, driving for pleasure, sightseeing, visiting museums, and visiting historic and prehistoric sites, as well as downhill skiing.

A medium rate[10] of recreational facility and resource growth, about 0.5% per year, would be needed to satisfy

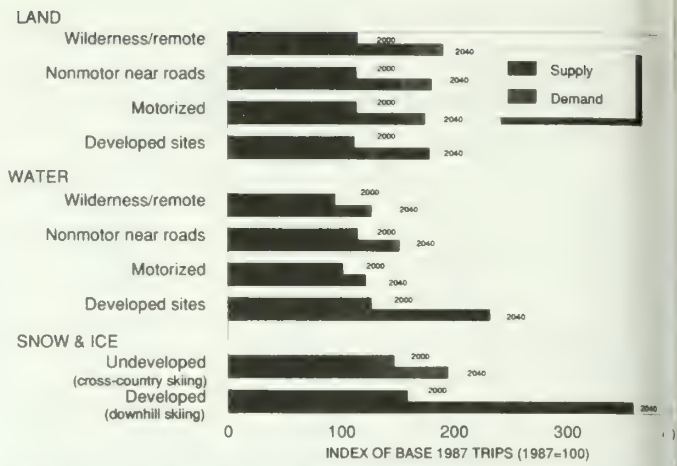


Figure 47.—Projected indexes of outdoor recreation demand, supply, and shortages by category, 2000 and 2040.

preferred demand for developed and primitive camping, backpacking, picnicking, family gatherings, walking for pleasure, collecting firewood, collecting berries, seashells, and mushrooms, horseback riding, and photography plus canoeing or kayaking, water skiing, rowing, paddling/other boating, sailing, and lake, river, or ocean swimming, as well as cross-country skiing.

Maximum preferred demand for nature study and wildlife observation and photography can be satisfied with a 0.25% growth of recreational facilities and resources per year. A low growth rate[11] of recreational facility and resource will also satisfy maximum preferred demand for motorboating and rafting.

Wilderness

Demand and Supply Outlook

Assessment of "demand" for wilderness is a difficult task since it involves many possible uses, some of which do not easily lend themselves to traditional measures. Public use of and benefits from wilderness occur both on- and off-site. That is, visitors may travel to a wilderness area for on-site recreation activities such as backpacking or fishing. They may also travel to wilderness for on-site uses such as research, human development, or for spiritual purposes. All these uses involve a physical presence of the user at the wilderness area.

Alternatively, some forms of wilderness use do not require an on-site visit yet benefits are derived as surely as the recreational backpacker or those seeking a spiritual experience derive benefits. These benefits include simply knowing that wilderness exists and that it will be available for future generations. Off-site benefits may also be derived by assigning an intrinsic value to wilderness—wilderness for wilderness' sake. All Americans, knowingly or unknowingly, derive value from wilderness because it helps to preserve our environment, whether it is protecting the diversity of plant and

[9]*A high rate of recreational facility and resource growth is defined as growth approximately equal to the expected growth rate of population 12 years and older to 2040: slightly less than 1% annually, or a total growth of about 43% by 2040.*

[10]*A medium rate of public recreational facility and resource growth is approximately one-half of the expected population growth rate: about 0.5% annually, or a total growth of about 22%.*

[11]*A low rate of public recreational facility and resource growth is defined as approximately equal to one-fourth of the population growth rate: slightly less than 0.25% annually, or a total growth of about 11%.*

animal life or maintaining clean air and water. Research and monitoring conducted in wilderness improve land management and quality of life.

The growth rate in on-site recreational use of wilderness has apparently leveled off over recent years following several decades of very rapid growth. Whether this recent trend will continue is unclear, but it is probably tied to a changing national demographic profile. Though less measurable at this time, the on-site use of wilderness for certain nonrecreational purposes may not follow strict demographic trends. And, other off-site uses of wilderness, particularly those that support the quality of the environment in which we live, will likely never diminish.

Assessment of the "supply" of wilderness is also challenging since the act of designating wilderness acreage does not necessarily translate into the production of wilderness experiences. Wilderness character is often quite fragile and may be threatened from overuse, especially recreational use within an area but also from sources outside an area. Further, because of the many purposes of wilderness, not all areas within the National Wilderness Preservation System (NWPS), nor every acre of any single wilderness area, are available for all uses. Recent legislation has begun to more specifically stipulate some of the more important uses for new wilderness areas.

Because the NWPS is composed of federal lands only, wilderness areas are not uniformly distributed throughout the nation. Unlike local and state parks, wilderness areas exist where available undisturbed lands are, and they cannot be flexibly located to meet the recreational or environmental needs of any certain local population. Most designated wilderness is located west of the Rocky Mountains, predominantly in Alaska. As a result, for much of the nation's population, using a wilderness area for recreation takes much more travel time and money than would be required to use state or local recreational areas. Also, the ability to preserve ecosystems, clear air, and clean water favors the western half of the nation.

Additional acreage has been identified with the potential to become designated wilderness, most of it located in western states and Alaska. Some of these potential wilderness areas would add to or strengthen the diversity of the ecosystems represented in the NWPS, particularly warm and cold desert ecotypes. However, because they are not federal lands, other ecotypes, such as prairie grasslands, are not well represented now and may never be.

General Observations Concerning Projected Demand and Supply Imbalances

What are the policy implications if recent trends of resource and facility availability continue into future years? And, what are the management implications of the imbalances that may result between what people would **prefer** to do and what they are **able** to do? Lastly, what are similar policy implications for wilderness management? A continuation of recent trends implies commitments to current policies and current levels of public spending for outdoor recreation. The gaps between future demand and supply may widen considerably for some activities without a change of budgets and spending. In some cases, federal and state spending levels have been decreasing. For other activities, future demand/supply gaps are more likely to be negligible to modest. Whatever the impact, however, continued substantial public sector spending will be necessary if recreation and wilderness opportunity trends are to continue.

Deviating from past trends can involve even more changes in public budgets and private investments. Without deviating from past public sector trends, it is highly likely that some undesirable consequences will occur and benefits may be foregone. But, even a small change to address projected gaps may mean many millions of additional dollars. The alternative future facility and resource growth scenarios presented above indicate various federal supply alternatives from minor decreases to an over 40% increase through 2040. Even a decision to maintain all facilities and resources at their current quantity and quality would result in a major shift away from some of the decreases in facilities and resources experienced since the 1970's.

If projections for natural resource-based outdoor recreation are indicative of the future, national forests, especially in the East, along with other public and private lands, must be managed more intensively for dispersed recreation. Primitive camping and backpacking, hiking and horseback riding, nature study, and wildlife observation are all projected to experience large shortages, particularly in the East. An increase in public awareness of recreational opportunities, improvement in roads and trails, an increase in interpretive and educational programs, management to reduce hazards and improve safety, and protection of natural, historical, and prehistoric sites and features will all be needed. These management objectives are manpower intensive and will require extensive education and training. If demand grows as projected, identification of heretofore unused sites and areas and perhaps purchasing additional acreage will also become necessary. Partnerships with other public and private entities will be essential. These objectives will require careful budget examination, and large increases may be needed to eliminate gaps. A much larger effort would be needed in land resource management and protection relative to water or snow and ice resources.

Along with resource allocation and management objectives, associated social, economic, and environmental implications will remain important. For example, providing opportunities near urban areas meets the majority of the American population's demand. If urbanization and migration patterns continue, more than three out of every four Americans will continue to reside in urban areas in the future. Most will be born and reared in a city and will have little knowledge of or sensitivity to natural environments. Without a public effort to increase outdoor recreation and wilderness awareness and supply in urban areas, the level of urban population interest in a number of outdoor activities may decline.

In contrast, however, demand for other forms of outdoor recreation may increase substantially as urban residents seek an "escape" or diversion from the pressures of urban life. Models and projections typically do not adequately account for such "preference" changes. Blacks participate far less than whites in a number of outdoor activities and tend to use state and federal lands for day use more often than other ethnic groups (Hartmann and Overdevest in press). Because blacks are more concentrated in central cities, they have a much lower effective supply of opportunities available to them.

Also, though opportunities will be available on private land to help satisfy projected gaps, landowners are likely to charge a fee for use and to post their land against certain (or all) activities. Thus, opportunities will be particularly limited for low-income people who may not be able to pay for private lands use.

The elderly may face even more severe shortages of preferred activities, including nature study, photography, walking, and other low-cost, less strenuous activities. This situation may challenge resource managers to provide recreation opportunities for the elderly. Disabled populations also often experience difficulties in using many sites.

The projections presented in this chapter are based on assumptions about the future and build from emerging trends. A trend discussed in chapter II showed that people are now taking more frequent but shorter trips for almost all activities. Thus, growth of trip demand is up and continuing to grow; but, this growth has a crucial relationship to availability of opportunities. Research has clearly demonstrated this dependence as has the modeling done for this Assessment. When viewed from this context, future consumption will not only depend on the value of time, preferences, income, and other factors but also on availability of opportunities, which mainly determines household trip costs. A recreation trip is widely considered the appropriate consumer unit in outdoor recreation. Therefore, future trip consumption is dependent on both demand-side and supply-side changes, including both provider and consumer technology. Several previous studies of outdoor recreation have based their conclusions mainly on demand-side changes. This approach leaves out the important effects that altering quantities of opportunities can have. As a nation, we have choices. One choice is to have either more or less outdoor recreational and wilderness opportunities. This Assessment provides some tools and results to indicate that choices made about future availabilities of opportunities can have important consequences.

One of the more important recreation demand-side trends concerns the value of time, which may not be adequately accounted for here. Leisure (nonwork, unobligated time) has declined 37% in the last 15 years while the marginal value of time has risen. Meanwhile, recreation, as a proportion of leisure, has increased since the early 1970's. The interpretation of this, in a period of rapidly increasing value of time, is that individual recreation demand, in general, is strongly inelastic. Also, in the future, older people will recreate more than older Americans in past decades because recreation will have been a more prominent part of their younger lives. The aggregate demand picture is somewhat different than a per capita or individual demand picture; and, certainly, demand growth is highly variable among activities. All of these emerging trends will need to be monitored carefully. As we learn more, adjustments in predictions and policies should follow.

Traditional quantitative trend analysis of the wilderness supply provides little insight into the future availability of wilderness or the degree to which it will meet national demands for wilderness outputs. Such changes are politically determined and depend upon Congress for allocation and federal agencies for management after designation.

Assuming that Congress continues to periodically add wilderness acreage on a state-by-state basis throughout the next decade, the recreational supply of wilderness, in general, may be adequate in terms of a national per capita acreage. However, the resulting distribution of the wilderness will require more time and energy by Americans to gain access to it, particularly among those living in the East. Even if lands now owned or controlled by agencies such as the Bureau of Indian Affairs or the Department of Defense were to become eligible for wilderness status, they, too, are nearly all within the western United States.

Without more specific legislative direction to (and policies from) federal agencies, many nonrecreational opportunities may continue to be underutilized or even compromised due to inherent conflicts among wilderness uses.

Without a plan to build the NWPS with specific objectives for ecosystem representation, some of the few remaining examples of unrepresented ecotypes may be lost. Both the supply and demand for recreation and wilderness are shifting as a result of changing demographic patterns. There are, however, no overall trends regarding anticipated gaps. What can be stressed is the need for accurate monitoring of changes, all the while trying to improve measurement to address discrepancies between demand and supply. In the case of wilderness, it is especially important to develop better measurement concepts to account for values, such as biodiversity, which are difficult to quantify.

CHAPTER V: SOCIAL, ECONOMIC, AND ENVIRONMENTAL IMPLICATIONS OF DEMAND-SUPPLY COMPARISONS

Introduction

The human ecology paradigm (Hawley 1950, Micklin and Choldin 1984, Park 1915, Theodorson 1961) provides the framework for this chapter's examination of the social, economic, and environmental implications of the findings and predictions presented thus far. The human ecology paradigm relates populations to their changing environments. As used here, it points to the consequences of continuing or changing trends in recreation and wilderness opportunities and resources. Interdependence among the paradigm's three major components, the human population (social), production and distribution (economic), and the natural (environmental), is examined. Demand and supply trends are also considered in order to identify implications for forest and range resources planning, management, policy, and research.

This chapter builds upon and adds dimension to the previous four chapters which describe current and projected demand for and supply of outdoor recreation and wilderness opportunities in the United States. Demand and supply is influenced by social, market, and governmental actions. In chapter III, "expected supply" was projected as the most likely outcome of the recent trends in availabilities of recreation and wilderness opportunities. In light of this possible future, this chapter addresses three specific objectives:

1. Identify social, economic, and environmental implications to today's society of the current availabilities and distributions of recreation and wilderness opportunities;
2. Assess the implications of trip and visitation growth that would likely result if recent trends in availabilities of opportunities are allowed to continue; and
3. Describe social, economic, and environmental changes that would likely occur if sufficient outdoor recreational opportunities were provided to eliminate gaps between the amount the American population would like to consume and the amount they could consume if recent trends continue.

One section each is focused on primary social, economic, and environmental factors or concerns which are likely to be affected by future recreation demand and supply changes. Possible gains or losses to society represented by these changes are discussed. Implications of the supply and demand for wilderness are also presented.

Situation Summary

Americans will continue to pursue their individual outdoor recreation interests into the next century. Some activities will gain popularity and others will lose; trend analysis helps identify which direction given activities will go. If the present trends in declining public land acquisition and private land closures continue, they will exacerbate an already disparate situation of accessibility. Not all segments of the American population have equal access to outdoor recreation opportunities. Geographic distribution of people and resources, income levels, usable leisure time, and other factors all prevent equal access, both individually and collectively. Crowding, already common in the East, can be expected to worsen unless more opportunities for outdoor recreation are provided at a pace that matches the growth in demand. If current trends continue, enough outdoor recreation opportunities will be developed to prevent shortages in supply for some activities but not all.

Social Implications: Changes, Imbalances, and Benefits

Outdoor recreation typically involves people interacting with each other and with a natural setting. Some segments of the population use natural resources for recreation at higher rates and in different ways than others do. This section examines emerging social trends in recreation contexts, the imbalances of opportunities that exist among various societal groups, and social benefits accrued through participation in recreation.

Major Social Trends and the Role of Recreation

Demographic trends point to intensifying stress on U.S. society. These trends include greater numbers of immigrants to be assimilated into society, more single-parent families and female-headed households, more families below the poverty level, and an aging population. Participation in outdoor recreation and wilderness activities may help ease social tensions resulting from these demographic trends. Failure to provide outdoor recreation opportunities could allow more stress to affect individuals, families, and society. These trends also add support to the assertion that outdoor recreation opportunities at the urban and local level are likely to be even more important in the future. Immigrants usually settle in cities, and those who are single-parent families and poor are likely to have more difficulty traveling long distances to seek recreation opportunities.

Godbey (1986) summarized eight major societal trends that are expected to affect recreation and leisure behavior. They are: (1) greater generational heterogeneity; (2) aging baby boom generation; (3) changing household composition; (4) increasing elderly population; (5) decreasing leisure time; (6) increasing economic restraint; (7) changing female work roles; and (8) increasing institutionalization of leisure. O'Leary (1985) summarized six major social trends of the 1980's that are expected

to significantly impact the American population and recreation situations in the future: (1) increased political conflict; (2) increased technological advances and innovations; (3) increased "experience erosion"; (4) increased depreciative behavior; (5) changing leisure activity patterns; and (6) increased social displacement. Cordell et al. (1989) identified other major trends including (1) shifting political power; (2) increasing self determination; (3) increasing value of time; (4) rapidly changing racial and ethnic mix; (5) new population shifts; (6) reduced attachment to the "land"; and (7) increasing regionalization.

These societal trends are sure to influence public recreational patterns and will likely shift the relative importance of recreation in American lifestyles. Trends away from the traditional family structure to more dual-income as well as single-parent households, and the overall decline in leisure, indicate that short, close-to-home trips will increasingly displace the extended vacation as a leisure norm. The combination of an aging population, advances in technology, and an emphasis on health and fitness indicate the potentially increasing importance of recreation activities to the elderly and the disabled. The apparent declining importance of the traditional family structure may indicate increasing importance of other aspects of life. Decisions concerning when, or whether, to have children and the increasing importance of careers also influence recreation patterns. Technological innovations indicate that a greater variety of recreation opportunities will be available generating new market segments, more diverse management challenges, and potentially increased conflicts among resource users. As litigation becomes more common throughout society, so too will the increase in the recreation setting. A proliferation of lawsuits has already begun and has caused some recreation areas to close or withdraw services for fear of litigation.

Such social trends, linked to recreation trends, indicate that the mix of popular recreational activities will likely become more diverse, with increasing importance attached to those activities which are popular with the elderly and those which can be consumed with small investments of increasingly scarce time. Those recreation areas close to large population centers also will be proportionately more heavily impacted.

Uneven Availability of Recreational Opportunities

American society is not homogeneous. It is made up of many different groups, reflecting various mixes of social factors and values. One individual can belong to many groups. Recreational opportunities and participation vary across these groups. The most important factors defining social groups, as related to recreational opportunities and participation, are age, sex, education, race/ethnicity, income, and rural/urban residence. Each of these factors and their relationship to recreational opportunities and participation will be discussed below. For analysis purposes in these discussions, representative "communities" across the United States with different social characteristics were defined to allow comparisons of the available local recreational opportunities. The intent of this analysis is to identify existing unevenness of availability across social groups.

Age.—Age is an important stratifying variable in American society (Neugarten and Hagestad 1976). Findings from the Public Area Recreation Visitor Study (PARVS) presented in chapter II illustrate how participation in outdoor recreation varies by age. Young people who commonly participate in more strenuous activities shift to less strenuous activities with advancing age. In later years, participation rates drop to very low levels and sometimes cease altogether. Water skiing, sledding, and other winter outdoor recreation can be considered primarily a young person's activity, while nature study, photography, walking, and other less strenuous activities are more common, but not unique to, the elderly. Approximately 11% of all Americans were over 65 in 1982; however, a projected 19% of the total population will be elderly by the year 2025 (Bureau of the Census 1983).

Comparing the age characteristics of U.S. communities with the effective amount and location of recreation opportunities (see chapter III) available to those communities produced some interesting and important results. Those communities with higher percentages of people under age 5 had significantly higher effective supply indices for most types of recreation opportunities. Other differences in effective opportunities also existed depending on the general age distribution among communities. This finding may indicate that families with young children have a propensity to live in areas with more nearby outdoor recreation opportunities.

In general, population age differences among the identified communities had little relation to differences in participation in outdoor recreation. This suggests a higher importance of age-related physical barriers as opposed to age-related differences in availability of opportunities. The incidence of barriers as a deterrent to recreation participation is becoming better recognized as more research results become known.

Gender.—Males and females differed in total rates of participation and in types of activities. The participation rates of males in activities such as driving off-road vehicles, backpacking, primitive camping, canoeing or kayaking, water skiing, and especially all forms of hunting were much higher than those of females. Females, on the other hand, more often engaged in horseback riding, walking for pleasure, sightseeing, and picnicking. A comparison of male and female differences in participation between the 1982–83 National Recreation Survey and the 1985–87 PARVS suggests that these gender differences have remained relatively stable during the 1980's.

Comparing communities with different gender ratios showed women had fewer recreation opportunities than did men for most land classifications and even more so across snow- and ice-based categories. Using a similar comparison for recreation participation, participation differences were found depending on the type of activity. Gender differentiation appears to manifest itself in

oth outdoor recreation participation and available opportunities. Some of these differences in opportunities etween male and female may be important.

Education.—Education is one of the primary determinants of "life changes" in society (Weber 1956). Educational differences in recreation participation have een illustrated earlier in the findings of this Assessment. Backpacking, nature study and photography, amping in primitive campgrounds, walking for pleasure, sightseeing, picnicking, and canoeing and kayaking were among the activities associated with higher educational levels. Also, changes in participation by various educational levels seemed to have occurred over ime.

The analysis also compared available effective recreation opportunity among communities with different overall educational attainment. Results varied depending on the characteristics of the recreation resource considered. For all land recreation opportunities, and most water opportunities, communities with more than 55% of their adults being high school graduates had much higher effective opportunity index values than did communities where less than 55% of the adults were high school graduates. Opportunities for snow- and ice-based recreation was much higher in those communities with high percentages of high school graduates and college-educated individuals.

For 10 out of 12 types of recreational opportunities, he supply per capita was greatest among communities with higher education levels. The exceptions were for developed water recreation opportunities for which supply availability was not significantly different across education levels, and nonmotorized water opportunities for which communities with the lowest levels of education, had the greatest effective supply per capita.

Race and ethnicity.—Race and ethnic groups differed n outdoor recreation opportunity and participation. Analysis of the effective availability of recreation opportunities compared to racial distribution showed significant differences. For example, communities with higher Hispanic populations showed high effective supply for almost all types of recreation opportunities. Communities with greater than 90% white population also showed high opportunity index values but for only half the recreation land types considered. In contrast, communities with a proportionately high black population showed low opportunity indices. This finding has greatest implications for considering equity in the distribution of opportunities for black populations, currently the largest racial/ethnic minority group in the United States.

In almost every outdoor recreation activity, the total percentage of whites participating one or more times annually exceeded that of all considered minorities. Blacks have continued to be very underrepresented in backpacking, horseback riding, driving off-road, primitive camping, developed camping, canoeing, water skiing, sailing, and all snow- and ice-based activities. Black underrepresentation in these activities appears to have been relatively stable in recent history. Communities with high percentages of whites had significantly higher participation indices for remote water activities and for all snow- and ice-based activities. But, these same communities had low participation indices for developed land and developed water activities. This finding was reversed for communities with high percentages of blacks.

The above information suggests a need to address the issue of low minority participation. Underrepresentation by minorities may have negative implications for race and ethnic assimilation into the larger American society. Clearly, inadequate availability of opportunities may cause low participation; but, other factors such as income, education, culture, or social differences may contribute. This complex question is becoming increasingly important as the social and ethnic mix within and among communities changes and as efforts continue for improving equal opportunities for all of society.

Income level.—One of the most important determinants of lifestyle choice is income. Income also influences recreation (Noe 1974, Reissman 1954). The analyses for this Assessment indicated, for example, that the highest participation in backpacking existed among both the highest and lowest income groups. Participation rates in nature study, photography, walking for pleasure, sightseeing, canoeing, water skiing, sailing, cross-country skiing, and downhill skiing were higher among high-income levels.

Communities with more families below the poverty level had significantly lower participation in all snow- and ice-based activities. These same communities had significantly higher participation in motorized land-based recreation activities.

In this analysis, both the percent of families and the percent of individuals under the poverty level were examined. Overall, communities with more low-income residents had greater effective per capita supply of developed and partially developed land opportunities and more opportunities associated with remote rivers and lakes. Roaded land and nonmotorized water recreation opportunities were more available to low income communities, but snow and ice opportunities were less available. No significant differences were found for other opportunity classifications.

Urban or rural residence.—Previous research and this Assessment have shown that outdoor recreation participation varies between rural and urban communities. Rural communities have tended to participate more in hunting and off-road driving. Urban populations tend to participate more in sailing and cross-country and downhill skiing. These rural and urban differences have remained relatively stable over time. However, if increased population movement to rural communities and exurbs continues, these differences may become less pronounced. At present, the participation differences seem mostly due to differences in opportunities available between rural and urban populations.

Comparison of the effective recreational opportunity between these communities showed that urban dwellers had less recreation opportunity than did rural residents, particularly regarding roaded and partially developed lands, intensively developed sites, wild and remote rivers and lakes, and river segments near roads. The opportunities available to urban populations were, of

course, related to how much land and water resources suitable for outdoor recreation were still available.

If urbanization and immigration patterns persist, then at least three-fourths of the American population will reside in urban areas in the future. This may mean that this growing population of urban residents could put tremendous pressures on rural areas in their attempt to recreate away from home. It is unclear whether this pressure will extend to areas providing the most remote types of opportunities. But, for the most part, the strongly urban communities contain much greater proportions of elderly, Blacks, Hispanics, and other racial and ethnic minorities. These groups typically fall disproportionately into lower income brackets. In addition to lower incomes, urban communities have more youngsters, juveniles, single-parent families, female-headed households, dual-income families, and unemployed. Opportunities for these urban populations must be highly accessible in the form of urban parks and areas close to the city.

Effects on American Society

Researchers have found that individuals, groups, communities, regions, and the nation are affected to varying degrees by participation or nonparticipation in outdoor recreation (Burch 1965, 1969, 1986; Cheek and Burch 1976; Kaplan 1960). Though difficult to quantify, such effects are important. Among the potential benefits to individuals are improved physical and mental health, increased self-esteem, a sense of well-being, and spiritual growth. Participation in outdoor activities can increase family interaction and foster cohesion. Potential benefits to society include increased social solidarity, increased ethnic and cultural assimilation, decrea social deviance, and increased national pride. Mos these benefits can also be achieved in ways other th through outdoor recreation. While it is difficult to qu tify a direct cause and effect relationship between o door activity and many of the identified social benef substantial evidence suggests that outdoor recreatio one of the better ways to improve the welfare of indiv uals and society (Ewert 1986, Kelly 1985). The reve is also true, lack of opportunities may exacerbate nee improvements of welfare.

For some activities, considerable shortages of opp tunities will occur. Based on the analyses done for t Assessment, these shortages are likely to affect some s ments of society more than others. Those activities w the largest predicted shortages are, in order: sightseei day hiking, wildlife observation, photography, a pleasure driving. These activities are widely popu among all social groups and are particularly import to the elderly, the disabled, and less affluent memb of society. If these shortages come to pass, as predict these and perhaps other segments of society will not perience the benefits that recreation participation offe

The social effects of not having adequate opportu ties may be most intensively and immediately felt at local level. Ultimately, however, these effects will gregate upward to regional and national levels. Gen ally, shortfalls in outdoor recreation opportunities w most severely affect residents of metropolitan ar where many socially and economically disadvantag people live. The possible and sometimes likely effe of insufficient recreation opportunities on several imp tant aspects of American society are discussed belo

Family stability.—Because outdoor recreation can p vide opportunities for family interaction and bondi

Family gatherings and other social engagements are important benefits from outdoor recreation.

Society may benefit from improved racial and ethnic relations through recreation participation.

(Carlson 1979, Holman and Epperson 1984, Orthner 1978, Rapaport and Rapaport 1975, Scheuch 1960, Snyder and Spreitzer 1973), it carries the potential to improve family stability. Historically, the primary users of public parks have been families (Szwak 1988). To the extent that outdoor recreation opportunities are not as available to families in the future, family stress may increase.

Crime and juvenile delinquency.—Research has shown that outdoor recreation reduces social deviance such as juvenile delinquency and prison recidivism (Ewert 1986). Thus, inadequate outdoor recreational opportunities could result in greater crime and juvenile delinquency. On the other hand, outdoor recreation sometimes provides opportunities for crime and deviant social behavior such as vandalism, littering, arson, and theft.

Social bonding and conflict.—Outdoor recreation and wilderness experiences influence the level of social participation and social group bonding (Burch 1986). The importance of social participation for personal well-being is widely accepted among social science professionals. Suicide rates are higher without cohesive social units and when people do not participate or interact within various social settings (Durkheim 1897). However, conflict can occur in any social situation, and outdoor recreation and wilderness uses are not exceptions. Conflicts between motorized and nonmotorized wildland recreationists are a well-known example. Various other competing and conflicting uses of natural resources do and will create on-site conflicts. Overcrowding will continue to cause conflict at some sites, such as whitewater rivers, if greater opportunities are not provided.

Ethnic and cultural assimilation.—Results of this Assessment show clearly that differences in recreation patterns depend, in part, on race and ethnicity. A more equal distribution of recreation opportunities and encouragement of equal participation among all races may be one way to better promote better interracial understanding and to reduce social friction. Insufficient outdoor recreation opportunities for immigrants may inhibit cultural interaction and deter assimilation into society.

Economic Implications

Recreation is tied in several important ways to local, state, regional, and national economies. It also has very significant economic efficiency and welfare dimensions (Alward 1986, Driver et al. 1987, Peterson and Brown 1986, Stoll 1986, Walsh and Loomis 1986). Secondary economic benefits are realized through increased employment and personal incomes; investment in recreation facilities and services; tourist and provider spending; regional and local economic growth and redistribution; and increased revenue and costs to local, state, and federal government (Kelly 1985, Walsh 1986). From economic efficiency and resource allocation perspectives, outdoor recreation and wilderness are major competitors for the use of forest and range resources. They can also contribute substantially to national welfare.

In this section, the economic implications of consumption growth and of projected opportunities shortages are discussed. This discussion focuses on seven economic factors or potential effects: (1) private sector profits including income to landowners; (2) property values; (3) recreation-related revenues to the public sector; (4) general revenues and costs to local governments; (5) recreation management costs; (6) management for other forest and range resource uses; and (7) redistribution of economic activity. The following discussion assesses

potential effects for each economic factor by comparing trend continuation with generating more recreation opportunity. The magnitude of these effects depends on the market share held by various recreation types and on the projected most likely future change of these market shares from the 1987 base to the year 2040.

Profits to the Private Sector

Land-based recreation.—Major opportunities for private sector business expansion will occur, especially in providing developed recreation opportunities and associated services. The market share for developed recreation is large; moderate to rapid growth in demand is projected. Accelerating private investments beyond recent trends will generate little additional profit since shortfalls below the public's maximum preferred demand are not expected. Roaded and partially developed recreation opportunities also will offer some significant opportunities for private entrepreneurs, particularly in sales of bicycles, day hiking equipment, sports clothing and shoes, purchases associated with sightseeing, and hunting gear. Near-road backcountry recreation is about 10% of the outdoor recreation market. With greater investment than in the recent past, more rapid growth in equipment demand should occur for hiking, horseback riding, wildlife observation, nature study, photography, and related activities.

Because wilderness use represents only about 2% to 3% of the outdoor recreation market, the overall economic effect of an increase in designated wilderness should be relatively small. A moderate expansion of designated wilderness will increase economic opportunities for outfitters and guides. Opportunities for sales of backpacking equipment and clothing will continue, but a significant market could develop for information to facilitate wilderness use. The greatest opportunity seems to be for information about trails, natural areas, historic and prehistoric sites, and significant scenery.

Water-based recreation.—Water recreation opportunities will offer substantial private sector growth potential. Strong demand for access to and accommodations near water, including marinas, pool complexes, nonpool swimming areas, and other facilities, will continue. Club memberships, food and rental concessions, recreation residences, and equipment sales and rentals can generate substantial revenues. Sale or rental of motorboats, water skis, and a host of new motorized water equipment can create moderate potential for increased private opportunities on lakes and rivers with road access. Much of the revenue from remote site, nonmotorized water recreation is likely to come through guide and outfitting services and through raft and other equipment rentals. However, the percentage of outdoor recreation which occurs on remote river sites is only 6%, limiting its overall potential for economic growth. Investment growth at rates greater than recent trends would net only modest additional profits.

Snow and ice.—Though their current overall market share is less than 1%, winter sports present an excellent private sector economic opportunity. This is particularly true for downhill skiing because per person expenditures are typically quite large. A substantial increase, 259% by 2040, is projected for downhill skiing and should fuel this market. Lodges, resorts, rentals, food, ski lifts, and instructional services are highly marketable. Transportation from airports and metropolitan areas to winter sports locations will also create business opportunities. Because motorized winter recreation is

Increasing demands for some forms of outdoor recreation will create opportunities for private enterprise.

only 0.1% of the total recreation market, its overall economic effects will be minor. The market share of backcountry snow and ice recreation is less than 1%, and the small market and widespread availability of land and trails where climate is favorable limit private sector opportunities. The principal opportunities will occur in equipment sales and rentals and in sales of winter sports clothing, with some additional opportunities in outfitting. Acceleration of opportunities for cross-country skiing will increase private sector profits.

Income to landowners.—Income to landowners from fees and leases offers another opportunity for private sector profit. Increasing pressure on public lands for nonconsumptive uses and closure of some private lands will create financial opportunities for landowners who want to open their land to the public for daily, seasonal, or annual fees. Additional income will be gained by charging for some road and off-road uses. Landowners also will have opportunities to capitalize on the increased demand for campsites and semideveloped recreation. Owners of land near wilderness and backcountry areas may realize some economic benefits through use of their land as staging sites for guided and outfitted trips, for grazing pack animals, and as trailhead camps. Landowners along lakes and streams will also benefit by charging for camping and boat access. For snow and ice recreation, opportunities are more limited, although some landowners may be able to lease their land to snowmobile clubs and cross-country skiing enthusiasts.

Property Values

Values of developed properties and those lands with development potential near attractive public or private recreation areas should increase relative to other land values. Rising demands for recreation using partially developed and roaded public and private areas are likely to significantly offset decreases in the value of land for agriculture in selected areas. This could have a stabilizing influence on rural land prices. Properties which provide road or trail access to public or private recreation lands are likely to appreciate in value because recreation opportunities associated with these lands are attractive to second-home buyers. Historically, new housing units have sold at higher prices in areas where there are opportunities for backcountry recreation. Also, commercial and industrial lands located near outdoor recreation opportunities may increase in value because access to recreation is an important factor affecting some business location decisions. Increased demand for wilderness is likely to have a significant effect on nearby property values.

Revenues to the Public Sector

Land.—Developed land-based recreation sites offer the greatest immediate potential for increased revenue for public agencies. Demand for the use of developed sites is projected to rise steadily and users generally are willing to pay fees. Revenues from direct management of sites or through leasing of sites to private concessionaires could be significant and substantially defray some management costs. Next to developed sites, motorized and nonmotorized recreation in roaded and partially developed forest and park areas represent the greatest public sector revenue opportunities. Well designed fee structures (assuming authority to charge fees) will increase revenues for agencies at all levels, but especially federal and state. Charging fees for use of wilderness or nonwilderness remote areas would require a change in policy, and collection would be costly unless paid through an annual pass or use permit. However, revenues for wilderness or nonwilderness backcountry are not likely to cover management costs. If opportunities for both developed and dispersed land-based recreation were increased to the levels the public would prefer, over 70 million additional recreational trips would result by 2000, more than 400 million by 2040. If substantial fees were charged, these increases would not occur because imposing fees would result in decreased consumption. The amount of this decrease would depend upon the fee level and other factors.

Water.—Since many lakes and rivers used in association with privately developed recreation sites are publicly owned, substantial revenue potential exists. Motorized and developed-site water recreation is about 12% of the total recreation market and projected market growth is moderate to high. The greatest opportunities will come from permits to private facility operators and fees paid by individual boaters. Recreational facilities, including swimming pools, will be especially attractive; but, expansion at rates about equal to recent trends will be adequate.

Snow and ice.—Potential exists for major increases in revenue from permits for privately-operated, developed winter recreation sites on public land. Making more public land available at rates equal to recent trends for downhill ski areas, if operators could be charged fair market value for use of the public land, could produce significant revenues. Fees could be charged for use of public snowmobile and cross-country ski trails, but an expected low volume of participation and relatively small number of accessible sites limit these revenue possibilities. For wilderness or backcountry winter recreation, opportunities for charging fees are limited. Even with the high projected growth for backcountry winter recreation (more than 200% in 50 years), little added public revenues are likely. New, innovative, and publicly acceptable means for charging and collecting user fees may increase revenue possibilities for dispersed recreational activities.

Revenues and Costs to Local Government

Land.—Growth in land-based recreation will stimulate more spending by local government, but revenues from fees and taxes will also increase. Expected strong participation growth in day hiking, visiting historic and prehistoric sites, running, jogging, bicycling, picnick-

ing, and family gatherings will heavily pressure local government sites and facilities. But, for these activities, net revenue potentials will be limited by high development and maintenance costs. The development of permanent or second-home residences will broaden local property tax bases. However, for both developed-site recreation and home development, the costs to localities for roads, utilities, law enforcement, and health services will be substantial and may more than offset revenue increases in the short run. While wilderness and backcountry users spend about the same amount in local areas as do other kinds of users, they are far fewer in number and generate limited total revenues. However, they typically do not put extra service or road use demands on local governments so a modest net local tax gain may be realized. Expansion of opportunities at rates greater than recent trends for wildlife observation and nature study, horseback riding and day hiking, visiting historic sites, and family gatherings will encourage more rapid participation growth, but at relatively low costs.

Water.—Property taxes on water-related development will increase sharply while sales taxes generated from vacationers and second-home residents will be significant and should increase over time. On the other hand, local governments will be called upon to provide costly facilities and services. In the case of nonmotor water recreation, sales taxes by outfitters, guides, and equipment sales and rental firms will provide some small revenues. Installation of pools and other water facilities in local parks and recreation sites will be important for urban residents, but these facilities will be costly to maintain.

Snow and ice.—Even though snow and ice recreation is projected to increase significantly, local sales tax revenues will increase very little because overall local spending by participants is relatively low, except for downhill skiing. In those relatively few locations where developed winter sports sites exist or might be built, substantial sales and property tax revenues may develop. However, road maintenance, law enforcement, and service costs will likewise be significant. Nonmotorized, backcountry winter recreation typically has limited private business impact and will not be a source of local government revenues nor impose additional costs.

Recreation Management Costs

Land.—On public lands, overall costs of management will increase significantly. More services, law enforcement, and interpretive personnel will be needed to accommodate greater numbers of visitors and a variety of activities including trail use, river running, nature study, skiing, camping, visiting museums, and visiting historic and prehistoric sites. More intensive visitor management will be required to prevent conflicts among users, such as commercial and private boaters, hikers and horseback riders, motor and nonmotor users, and consumptive and nonconsumptive users. More management to minimize damage to fragile natural sites and to facilities will also be necessary as user numbers grow. Additional investment in facilities will be require along with associated long-term maintenance, especia trails, historic site access, roads, and overnight and da use developed sites.

Private landowners who make their land available the public, whether for a price or free of charge, also w incur substantial costs for liability insurance, road a fence repairs, and posting signs.

Expanding opportunities for roaded, partially dev oped environments for hiking, bicycling, sightseei and most general forms of dispersed recreation will p the most serious budgeting challenge. Expanding the opportunities at a high rate of about 1% per year wou be necessary to prevent future shortages. Accounting possible inflation, a budget growth of 5% to 7% per ye may be needed.

Water.—A direct conflict often arises between mo and nonmotor recreationists on rivers and lakes. Me ing the need for visitor management in such cases, esp cially at the more accessible and popular areas, cou be quite costly. The costs of operating developed wa sites will increase some, but these should not be exc sive. However, the cost of liability insurance will significant.

Snow and ice.—The relatively small number of use and a trend toward placing responsibility for safety the individual should help stabilize the costs of mana ing winter recreation. The need for avalanche contr and other routine backcountry snow management w continue, of course. Some increased costs may occur b cause of demand for information on winter opportu ties, less than optimum snow conditions, and safe measures. Public and private expansion of dispers winter opportunities will be needed to prevent a pr jected shortage. The role of the private sector in provi ing dispersed winter opportunities may becom relatively more important.

Management for Other Forest and Range Resource Us

Just as timber harvesting or mining sometim preclude or diminish the value of land for some for of recreation, increased recreational use can affect co modity production. Expansion of the NWPS preclud timber harvesting and mining. Intensive recreational u also could preempt noncommodity uses of the land su as reservations for scientific study. In rural areas whe second-home development is popular, the acquisiti and dedication of land for recreational use will foreclo commercial and residential development. Recreation uses of private lands adjacent to public forests or gras lands sometimes preclude altering the landscapes those lands by mining, timber harvesting, or controll burning.

However, the extent to which recreation actually co flicts with commodity and noncommodity uses a values is directly related to the intensity of manageme to avoid conflicts. For example, reductions in timb production in one area of high recreation value mig be offset by intensifying timber management on are

of higher timber productivity and lower recreation potential.

Developed-site recreation typically does not involve extensive use of forest and range so conflicts with other uses are usually less obvious. Increased recreational use of reservoirs for which the main purposes are power generation, navigation, or flood control often results in pressure to maintain lake levels. This results in some decrease in power and flood control benefits.

Recreationists should encounter few conflicts between backcountry winter recreation and other uses. However, motorized winter recreation occurring off-road may adversely impact some resources; careless off-road vehicle use can damage tree plantations and interfere with wildlife. Concerns about maintaining a forested view at winter resorts may result in some loss of timber production.

Overall, the highest predicted growth of forest recreation participation by 2040 is indicated for backpacking (+98%), day hiking (+129%), visiting museums (+87%), visiting historic sites (+104%), family gathering (+102%), sightseeing (+85%), developed camping (+95%), rafting/tubing (+167%), and downhill skiing (+259%). These activities depend upon scenic and clean environments, linear access, and site protection (particularly critical for archaeological sites). Increasingly over time, the public area recreation visitor is going to be sensitive to commodity and extractive resource uses and will likely cause impacts on the degree of and methods by which these nonrecreational uses will be exercised. If predicted shortages are eliminated in the future, more area and resources will, thus, be impacted, particularly as they are affected by scenery protection and provision of linear access.

Redistribution of Economic Activity

Investments in outdoor recreation areas, facilities, and services can result in redistribution of economic opportunity from one sector of the economy to another, or from one region to another. Thus, in assessing economic costs and benefits, it is important to look at the distributive effects of satisfying recreation demands.

Land.—In terms of land resources, the greatest opportunity for expanding local economic activity lies in recreational pursuits involving extended stays such as those at ski resorts or campgrounds. Because opportunities are typically widely scattered, redistribution of economic activity is usually modest. Past economic growth patterns among retail, service, and manufacturing sectors have not been heavily impacted by outdoor recreation visitation and spending. More recent trends have shown greater development of private accommodations, food and other services, and transportation associated with recreation. Increasingly, states and local areas are looking to recreation and tourism as a means of stabilizing their economies.

An expansion of recreation opportunities to meet projected demand would result in an increase of more than 400 million recreational trips per year—most of them to rural areas. Local spending associated with these trips would likely exceed $8 billion per year, with an expected impact on total industrial production of between $10 billion and $12 billion. With farm and other rural incomes expected to continue to decline, recreation may offer a viable economic complement to agriculture, particularly if farmers can take advantage of increased opportunities to charge fees for recreational use of their land. Similarly, many of the areas suitable for potential expansion of nonmotorized recreation outside of wilderness are in areas where farming is a large component of local economies. A substantial increase in demand for this kind of recreation is projected, potentially resulting in greater long-term economic activity as service and retail sectors respond to demand. For wilderness and backcountry recreation, redistributional effects will be less because of their small market share, and most of the effects will occur in the West.

Water.—Retail sales, amusement, and recreation businesses tend to be more prevalent in areas with the greatest potential for expanding developed, water-based recreation opportunities. Thus, increasing demand will cause a moderate growth in business opportunities in these areas and lead to some business and income redistribution. Since retail service and recreation-related businesses are weak in areas where most of the potential for nonmotor, water recreation supply expansion exists, substantial redistribution of income and employment are not anticipated.

Snow and ice.—Numerous service, retail, and recreation enterprises already operate in those areas with the greatest potential for expansion of downhill ski areas and other developed winter recreation facilities. Thus, growth in developed winter sports should result in little, if any, redistribution of economic activity. Because of its low market share, backcountry winter recreation can produce little additional business activity in areas where these winter opportunities exist. Most winter recreation equipment, clothing, and other needs are purchased where people live, not where the activity takes place.

Environmental Implications of Increased Recreation Demand

Compared to more consumptive uses, such as timber harvesting, mining, and grazing, most outdoor recreation and wilderness uses have relatively low impact on natural systems. These uses also provide opportunities for people to reinforce their ties to the natural environment, and they provide opportunities to monitor the health of natural systems. Driver et al. (1987) have identified several benefits of outdoor recreation and wilderness uses, including an improved esthetic quality, greater environmental awareness, and stimulus to preserve natural systems. Outdoor recreation programs, for example, may help preserve areas of high scenic and ecological quality, historic areas, and sites especially valuable for scientific study and outdoor education. The addition of parks and open space in urban areas can significantly improve the quality of the environment in

populated areas. Moreover, participation in outdoor recreation creates support for efforts to preserve species diversity and to maintain water and air quality. It also fosters land stewardship (Driver et al. 1987, Rolston 1986).

On the other hand, some forms of outdoor recreation can adversely affect the natural environment (Clark 1986, Cole 1986, Rolston 1986, Stankey and Manning 1986, Williams and Jacob 1986). Sustained or repeated heavy use for certain activities can degrade land, water, air, scenic values, and fauna. Environmental impacts can occur across a variety of natural conditions, components of the natural environment (soil, water, vegetation), ecosystem types, spatial scales (site-specific, area-wide, system-wide, and national), and the ecological hierarchy of population, community, ecosystem, and landscape. Environmental interactions are complex. Typically, direct impacts are local, occur along trails and in and around campgrounds, and are limited in extent. However, when thousands of visitors congregate in an area, the effect can be quite large and significant. Indirect effects can sometimes extend throughout an entire watershed.

The designation of additional wilderness areas can provide general benefits to the environment by protecting areas from road development, timber harvest, and development that could lead to an array of adverse impacts. Additional wilderness areas are needed if one goal of the NWPS is to preserve as diverse an array of ecosystems as possible—particularly prairie grassland ecosystems. On the other hand, wilderness designation can attract increased visitation resulting in some degradation of the natural environment.

Some specific impacts of recreation likely to occur through increased participation are discussed below.

Esthetics and Alteration of the Natural Landscape

Increased recreational use may reduce esthetic quality because of construction, facilities, and site "hardening" to accommodate intensive recreational uses. Additionally, increased use pressures existing areas to exceed their carrying capacities. Although some efforts are being made to reduce the scale of development and to remove visually intrusive structures at some sites, some development will inevitably occur in order to provide the conveniences and health and safety protection that recreation visitors increasingly seek. The degree to which these effects reduce the quality of the recreational experience is a matter of individual preference and perception.

On the other hand, additional recreational use in high quality settings can raise the environmental consciousness among those involved. This heightened awareness can, in turn, result in demands for higher visual standards in and around recreation sites and facilities. This can ultimately lead to political action to influence or reverse esthetic degradation not only at the recreation site, but also in the communities where people live. Examples include ridgeline development laws enacted in mountain resort areas, billboard regulation along scenic byways, and litter control in suburbs.

Additions of recreational facilities and more efforts to preserve the resources necessary to prevent opportunity shortages can help protect the quality of rural landscapes and add to the inventory of forested landscapes. Increased management to help reduce opportunity shortages for activities such as backpacking, photography, nature study, wildlife observation, sightseeing, and day hiking can help improve overall landscape quality. Greater preservation of scenic, historic, and prehistoric areas will stimulate better protection of the visual resource. Designation of scenic byways, as recently enacted federal legislation would permit, may have very widespread positive benefits much beyond the immediate environs of the affected roadway.

Soil and Vegetation

Recreation has been linked to soil compaction and erosion (Ketchledge and Leonard 1970, Manning 1979, Weaver and Dale 1978). Generally, such impacts are localized and limited to strips along trails and around campgrounds. Compaction and erosion impacts are greatest in the early stages of use (Cole 1982, 1986). Thereafter, the negative impacts of additional use slow considerably (Stankey and Manning 1986).

Recreation's impact on vegetation follows the same pattern as for soil. That is, initial use can cause substantial vegetative decline after which additional use causes comparatively little added change. Trampling of sensitive plants may allow more resistant or undesirable species to become more abundant (Crowder 1983). Trampling can reduce the vigor and diversity of plant species. For both soils and vegetation, foot traffic has less impact per visit than either horses, bicycles, or motorized vehicles.

Activities with moderate to high levels of expected growth that can impact soils and vegetation include horseback riding, bicycle riding on trails, backpacking and hiking, and developed-site use. Though hiking and backpacking trips may increase in existing wilderness areas, the most severe impacts may already have occurred. However, horseback riding and increased use by outfitters who use saddle horses or pack animals can have some adverse consequences. Similarly, some portion of the expected increase in bicycle riding can be attributed to mountain bikes. The growing use of these machines can contribute to additional soil and vegetative damage. Continued trends of reduced budgets for trail maintenance, developed-site management and refurbishing, and enforcement personnel may allow negative recreational impacts to go uncorrected.

Whether localized ecosystems will be negatively affected by the projected moderate increases in activities, such as firewood and berry collecting, will likely depend on management philosophies. The foot and vehicular traffic inherent in these activities could possibly contribute to trampling and erosion.

Even though off-road vehicle (ORV) use is not projected to grow rapidly, the severe adverse impacts to both

Many forms of outdoor recreation have a substantial influence on the economic development of local areas.

egetation and soils caused by ORV's make it an impor- ant activity to monitor. The degree to which increased ORV use will occur in ecologically fragile areas, such s sand dunes, will determine, in large part, the extent o which this recreational use may become problematic. Recent trends have been to close more areas to ORV uses. ORV user groups have responded with political pres- ures and educational programs for users.

If expanding trail systems to improve backpacking and ay hiking means new construction in existing NWPS ands, additional vegetation and soil damage may occur. However, if this expansion is associated with protection f additional lands, or if it occurs through alteration of xisting rights of way, such as railroad and utility cor- idors, the gains from protection may equal or outweigh osses from increased use.

Expanding road systems necessary to reduce shortages f opportunities for pleasure driving and sightseeing can ave severe negative soil and vegetation impacts. Black- opped corridors especially may have severe negative mpacts on vegetation (Willard and Marr 1971). Also, npaved roads are notorious as a source of sediment in treams, thus influencing stream vegetation (Irland 1985, White and West 1980).

Wildlife

In general, remote environments contain choice wild- ife habitats characterized by the absence of man, noise, ollution, and other anthropogenic alterations. Other actors also determine the presence or absence of wild- ife. For example, various species require minimum abitat sizes. The grizzly bear requires as much as 2,500 km^2 on which it roams for food (Seruheen 1986). The egetational composition of an area and its geographi- al location also determine a wildlife species' presence, umbers, and health.

Maintaining the full spectrum of wildlife species is advocated by most ecologists. The loss of unaltered areas to development has caused some species to decline, becoming rare, endangered, or extinct. For example, the Colorado squawfish (*Ptychocheilus lucius*), once found throughout the Colorado River system, is now largely limited to portions of the upper basin in the states of Colorado and Utah. The species habitat has been fragmented by dams and altered by regulated streams (Haynes and Bennett 1986). Additional species face similar fates in threatened environments.

High density forms of recreation can create air, water, and noise pollution, and often garbage dumps (Boyle and Samson 1986). Wildlife often habituate to human presence so disturbances may be minor. Feeding of animals by recreationists usually creates unnaturally high densities of animals. This may amuse the person doing the feeding because he or she enjoys viewing and interacting with the animals. However, negative consequences can arise if animal populations become dependent on human instead of natural food sources. Animals which become too tolerant of people may damage private possessions or property and public facilities. Close contact between people and wildlife can also increase the incidence of animal-borne diseases such as plague and rabies. These problems often force health and wildlife authorities to destroy offending animals.

Outdoor recreation can affect wildlife populations through habitat alteration, disturbance, or direct mortality. Many reports of impact have been made, but the literature lacks quantitative assessments of long-term effects (Boyle and Samson 1986). Research on recreation's effect on wildlife sometimes presents contrasting conclusions based on the same observations.

The expected growth in backpacking and day hiking could negatively affect wildlife directly through losses of soil and vegetation, increased animal feeding and litter, especially plastics, and increased human presence.

Some positive effects may accrue indirectly. For example, a greater awareness of natural systems may stimulate greater public concern for wildlife.

Increases in developed camping and picnicking, and the garbage often generated as a by-product of human presence, can affect animals by increasing their dependence on that garbage for food and by eliminating their fear of humans. This latter consequence can be dangerous to humans where raccoons, bears, and alligators are involved. Long-term effects on animal populations are not well-known.

Increases in vehicular recreation can affect animals directly by increasing the likelihood of death by collision and indirectly by damaging food or breeding areas. Several motorized activities are predicted to grow moderately—pleasure driving, sightseeing, and motorboating. Off-road use is predicted to grow slowly although its effects on wildlife may be profound (Boyle and Samson 1986). More trips to forest sites for almost any activity can impact wildlife populations.

Water and Air Quality

Recreational development and activity can alter the amount of sediment in streams (Gosz 1982). One consequence of severe soil compaction is erosion into aquatic systems (Manning 1989). Transported sediment can carry heavy metals, nutrients, and organic compounds which can collectively or individually cause problems or worsen existing problems in aquatic systems (Burby et al. 1983). Nutrients can increase plant growth, thereby reducing dissolved oxygen. This produces an environment that favors plant over animal life. Increased sedimentation stemming from soil compaction, disturbance of vegetation, and bacterial contamination from human waste all degrade remote waters.

Including areas in the National Wilderness Preservation and Wild and Scenic Rivers Systems helps protect the quality of some rivers. In addition, greater demand for water opportunities has pressured governments and industry to improve water quality in rivers, especially those near urban areas.

In some localities, especially in very popular developed sites and along well-traveled scenic corridors, air quality can be reduced by automobile exhaust and smoke from campfires. Because most recreation-related travel is by automobile, increases in recreational trips will create more air pollution problems. Developing more recreation areas will affect air quality. More areas may disperse usage and, thereby, minimize pollutant accumulation. Opening new recreation areas may also create air pollution problems where they did not exist before. Locating new areas near urban centers may limit travel miles which could minimize pollution, or the eventual congestion could worsen local air quality problems.

All water activities are expected to grow at least moderately, and rafting and pool swimming are expected to more than double in the next 50 years. Crowding in some areas, especially remote water areas, and some increases in plastic and other litter can reasonably be expected. Overuse of some fragile areas could result from growth in canoeing, kayaking, and rafting. In addition, growth in motorboating and water skiing will add to pollution in some lakes and rivers.

Recent trends in water quality improvement should continue for the projected growth in water-based recreation. Greater demands for further improvements, especially in and around urban centers, can also be expected and will likely impact water quality legislation, monitoring, and related programs.

Wilderness

The current wilderness situation has several distinct social, economic, and environmental implications resulting from both allocation and management issues.

Social Implications

Wilderness may be considered our social heritage. It provides a multitude of social benefits, from recreation to human development and rehabilitation to spiritual enrichment. It provides opportunities to examine and learn about past cultures and natural history. If insufficient wilderness is allocated, or if it is managed so that these opportunities are diminished, the nation may lose an important part of its heritage and the benefits it can provide to future generations.

Increasingly, the focus on wilderness concerns its quality, whether for recreational or nonrecreational uses. An inadequate supply of wilderness, particularly if it is not well managed, may result in Americans being unable to enjoy a wilderness environment as intended by the Wilderness Act. Distinctions between wilderness and nonwilderness lands, resources, and experiences can become blurred.

Economic Implications

Government agencies will not experience any direct revenue losses as the growth of wilderness recreation slows because no fees are charged for using wilderness. Less growth, however, may affect suppliers of equipment used in wilderness recreation as manifested in slower sales growth. Slower growth of wilderness recreation is not expected to significantly affect commercial outfitters whose business should increase with national demographic changes.

Because wilderness areas help protect air, water, wildlife, and other environmental attributes, it provides value to the economy in several ways. Wilderness watersheds help store and release water with minimal treatment requirements for later agricultural, residential, and even industrial purposes. Clean wilderness rivers are often critical spawning grounds for fish such as salmon which have commercial importance. Such spawning grounds would be very costly if not impossible to recreate. If the NWPS protects the widest possible sample of ecosystems, it then becomes a very cost-effective method

ır natural preservation of germ plasm compared to man-ıade gene banks.

nvironmental Implications

The quality of existing wilderness can be adversely ffected by both internal and external factors. The fed-ral government must actively enforce environmental gislation to protect ambient air and water quality, or lse wilderness ecosystems may suffer. If legislation reating new wilderness does not specifically identify ıe values which are to be protected by designation, then ther values may be given equal or greater attention. Fed-ral agencies must develop comprehensive management lans unique to each individual wilderness area so that nvironmental attributes, social experiences, and scien-fic research opportunities may be preserved. If recrea-onal use begins to expand again, as it seems to be oing, users must be educated in low-impact use chniques. Otherwise, increased crowding will damage oil, water, vegetation, and wildlife in these sensitive nvironments.

Conclusions

Comparing the demand for and supply of outdoor ecreation opportunities and wilderness resources eveals several important social, economic, and environ-ental implications for forest and range resources. These nplications represent both potential opportunities and ooming problems.

As a result of the way resources and population are istributed, recreation areas in the East generally sus-ain much more concentrated use than those in the West. his situation seems likely to continue. If the trend oward greater closure of private lands can be reversed, ıe added recreation opportunities may help alleviate ome projected increases in crowding of eastern recrea-on lands. Most pressure will be on supply of areas and acilities for physically active pursuits, particularly arm-weather activities on roaded, partially developed ands near population centers.

Other pressures will be for nonconsumptive uses such s sightseeing, day hiking, wildlife observation, and na-ure study. The largest specific opportunity shortages are redicted for sightseeing and driving for pleasure. Non-ecreational uses of wilderness also are expected to in-rease and, in some instances, may be incompatible with ecreational uses.

The importance of outdoor recreation to Americans is rowing. However, some segments of society have less pportunity for outdoor recreation and wilderness use. mericans who are elderly, less educated, a racial ninority, economically disadvantaged, or disabled and vho live in cities have fewer opportunities to partici-ate in resource-based recreation than do others. These roups' needs for recreation and constructive leisure nay be higher than those of other groups. This short-ge of recreational opportunities for some population egments is likely to have adverse social impacts. Less ecreation opportunity may result in less family stability, more crime and juvenile delinquency, less opportunity for social bonding, more social conflict, and slower ethnic and cultural assimilation among people with the above characteristics. These social impacts will continue into the foreseeable future unless changes are instituted to bring about a more even distribution of opportunities.

Outdoor recreation and wilderness resource trends also have highly significant economic implications. Major opportunities are projected for private sector investments in developed recreation opportunities and provision of associated goods, services, and information. These opportunities are projected for several categories of land, water, and snow and ice recreation. Landowners will have increased opportunity to realize profits by charging fees for recreational uses of their lands, and property values of areas near attractive recreation areas should increase. Because users of public recreation lands are generally willing to pay fees, some potential exists for generating additional revenue. These would come from fees for developed, land-based recreation and permits for private facility operators on developed water areas and developed winter recreation sites.

Additional revenue generation through increased fees is expected at all government levels. But higher management costs for dispersed recreation may offset many revenue gains. In some cases, increased management emphasis on recreation may decrease the use of agency lands for commodity production which can shift economic activity among sectors of our economy.

Most outdoor recreation and wilderness uses have relatively low direct impacts on natural systems compared with other consumptive resource uses. These uses also provide opportunities for people to reinforce their ties to the natural environment and can result in long-term gains in environmental awareness. Still, some forms of outdoor recreation can damage the land, degrade water, air, and scenic quality, and disturb wildlife. Soil compaction and erosion problems are typically localized as are vegetation impacts. The greatest damage may come from early use in new areas while further use of existing sites may cause little additional damage. Many wildlife species can habituate to human presence, but animal damage to possessions and facilities and transmission of animal-borne diseases are a possible result of increased recreation use. Some animal species require large tracts of undisturbed lands for survival; their populations could be reduced by significant recreation developments.

Overall, as society changes, so does recreation. Consequential changes are predicted to occur in the economy and the environment. The direction of these impacts can be influenced by management and policy decisions. The overall trend of increased use of outdoor recreation and wilderness areas indicates that policy actions must be taken to address the issues discussed above. In the remaining three chapters of this Assessment, our vision of opportunities to improve management, policy and practice, anticipated barriers to pursuing these opportunities, and specific recreation program needs for the Forest Service are presented.

CHAPTER VI: OPPORTUNITIES FOR IMPROVING THE AVAILABILITY AND MANAGEMENT OF RECREATION AND WILDERNESS RESOURCES

Earlier chapters identified a number of trends in outdoor recreation and wilderness demand and supply. The nation's population is increasing, and the demand for outdoor recreation and wilderness is growing with it. Moreover, the public is becoming more diverse as are the activities it pursues outdoors. However, many people do not participate in outdoor recreation or use wilderness for a variety of reasons.

Extensive land and water are available to help meet increased outdoor recreation demand, but many of these resources are located some distance from where the bulk of the population lives. Interest in outdoor recreation opportunities closer to home is a dominant current trend. Unfortunately, this is also where recreation and wilderness opportunities and open space are most limited and in jeopardy from urban and other development.

Projections of likely future situations for outdoor recreation show the likelihood of many gaps of varying magnitudes between what people would like to do (preferred demand) and what they may be able to do (expected supply). In the future, supply will be constrained even more than it is today. While these constraints and the gaps they may cause are problematic, they can also represent exceptional opportunities to improve the availability and management of outdoor recreation and wilderness resources. Opportunities sort into eight categories as follows:

1. Increase the availability of outdoor recreation opportunities;
2. Improve or protect the quality of outdoor environments, resources, and facilities;
3. Improve services to the public;
4. Expand coordination, cooperation, and partnerships;
5. Increase the supply of wilderness;
6. Maintain the existing quality of wilderness;
7. Increase management for nonrecreation values of wilderness;
8. Improve the technical and information base for recreation and wilderness management.

This chapter explores these opportunities.

Increase the Availability of Outdoor Recreation Opportunities

Making Better Use of What We Have

The first logical step to improving availability is to recognize and make better use of what is already available. Many recreational demands could be satisfied through increased or redistributed use of existing public lands. Private lands also can provide more public outdoor recreation. The demand and supply analysis in the preceding chapters has indicated that many activities which shortages are expected require little action oth than providing information about the opportuni means of access, and relatively simple facilities.

Public lands.—Existing public lands can accomm date substantially higher visitation without undue i pact on resources or other uses. While past attention h focused on over-crowding in a few areas, such as Yo mite Valley, the Grand Canyon's South Rim, and Ca Cod, large areas of existing public forest and range lar receive relatively little or no use. In many cases, n or improved access roads, facilities, trailhead parki and trails would greatly facilitate more use of curren sparsely used areas. Even some places experiencing re tively high visitation could accommodate greater u with few effects. Opportunities include more intensi management to separate conflicting uses, to educa visitors on low-impact backcountry techniques, and encourage off-season use. For example, by installing h showers in campgrounds, more people would visit so localities during cooler seasons.

Increased recreational use of some public lands cou put different users into conflict which diminishes t outdoor experience. Where needed, incompatible us groups can be separated in space and time. Sno mobilers and cross-country skiers, for example, can directed to separate trails. Mountain bikers and hike can use the same trails at different times of day or different days. Improving the knowledge among use of how their activities' impact other users as well as t resource may also help.

Rural private lands.—Rural private lands compri nearly two-thirds of the nation's land base and provi numerous outdoor recreation opportunities. The Pre dent's Commission on Americans Outdoors said, "Ma landowners have concerns, ranging from liability to va dalism, which prevent them from opening their lan to the public for recreation use" (PCAO 1987). Accor ing to findings from the National Private Landown Survey (NPLOS), however, 77% of private land pote tially available for outdoor recreation is closed to publ access. Many owners are purchasing land for their ow personal recreation or residences in a rural setting.

The greatest incentive to open land to the public, reported by landowners, is the opportunity to reali some economic gain. This especially seems true in are suffering from a depressed farm economy. By chargi a fee for public use, landowners could increase their i comes and help offset property taxes and other costs ownership, usually without affecting other uses of t land much. Public agencies, especially those in t Department of Agriculture, might provide landowne with information on the potential economic returns fro opening their lands to the public for a fee or throug leasing.

More Opportunities Close to Home

The nature of outdoor recreation trips is changing. Rather than a single long vacation to a distant place each year, more people now make shorter trips close to home. Thus, outdoor recreation opportunities close to urban areas are of growing importance and are likely to remain so for the foreseeable future. The challenge is to provide sufficient high-quality and diverse outdoor recreation opportunities for urban residents. Opportunities can be realized through land acquisition in and near urban areas for public recreation and through improved planning and provision of economic incentives to encourage the inclusion of recreation areas and open space in community development. Some public lands lie close to urban areas, particularly in the West. Examples are the three national forests adjacent to the Los Angeles-San Diego metropolitan areas: the Mount Hood National Forest near Portland, Oregon; the Mount Baker-Snoqualmie National Forest near Seattle, Washington; the Wasatch National Forest adjacent to Salt Lake City, Utah; and national forests and BLM lands near Boise, Idaho. These and other public lands provide those urban residents with excellent opportunities for outdoor recreation in natural settings.

Retaining open space in urban development.—As urbanization spreads outward from metropolitan areas and small cities, the retention of natural environments in and near urban and suburban areas becomes a particular challenge. The PCAO observed that recreation lands and waters and open space made communities and neighborhoods more desirable places in which to live, work, and play (PCAO 1987). Recreation areas and open spaces can be incorporated into communities and neighborhoods through more careful planning, which encourages the creation and expansion of greenways. Special attention is needed for resources such as rivers, floodplains, forests, and abandoned railroad rights-of-way in and near urban areas.

Acquisition and other methods of preserving open space.—In some growing metropolitan areas where sufficient recreation opportunities are not likely to be provided through private action, public acquisition may be the only certain way of providing the public with parks and open space. Public acquisition also may be needed to preserve areas of exceptional recreational, scenic, or ecological value in both urban and rural areas.

In many cases, however, land can be maintained as open space without acquisition. State and local agencies can preserve open space by exercising controls over development density, tax incentives to private landowners, and environmental and safety regulations. Prohibiting development in critical floodplains for example, can benefit wildlife habitat. Numerous federal, state, and local agencies and private land trusts have maintained open space through the acquisition of development rights or the purchase of access and scenic easements. These easements enable private landowners to retain some uses of their land while providing them compensation for the public benefits the land provides (U.S. Senate, Committee on Energy and Natural Resources 1981, 1982).

Improve and Protect the Quality of Outdoor Environments, Resources, and Facilities

A quality environment is essential for quality experiences out-of-doors. Many of the activities predicted to grow rapidly require high-quality environments and focus on study, photography, or other means to appreciate natural, historical, or prehistorical features. Many of the most popular and high-growth activities of the future rely on scenic beauty.

Protect Esthetic Quality

Esthetics is a comprehensive term for the effect that the interaction of all senses have with the natural environment. It incorporates smells, sounds, tastes, touches, movements, and views. Esthetics depend upon environmental integrity so that harmony is evident within and between natural systems, human developments, and uses (New York State Forest Resources Planning Program 1982). Esthetic quality attracts people to an area and increases their enjoyment of the outdoors.

Pleasant scenery is often the key to the quality of an outdoor activity. Opportunities to protect and enhance scenic resources on both public and private lands do exist. Through careful management of other uses, scenic qualities can be maintained and activities such as timber harvesting made more acceptable to the public (McGuire 1979). Necessary facilities, from roads to restrooms, can be designed and placed to maintain esthetic quality while enhancing enjoyment of the outdoors. Trails, too, can be located in such a way as to improve hikers' enjoyment. In a study of three recreation areas in Tennessee, Hammitt et al. (1984) found that trail users preferred an element of mystery as they walked—bends in the trail which hid the scene they were approaching. Hikers preferred trails which zigzagged across the forest edge rather than a trail that simply followed the edge of the woods.

Litter and signage are pervasive problems affecting the esthetic quality of the nation's recreation lands and waters. Land management agencies are hard pressed to keep up with the tide of billboards, nonbiodegradable containers, medical waste, and other trash that often blight many popular recreation sites and waters. Volunteers and civic organizations can assist in the collection of litter and the restoration of esthetic quality of federal, state, and local recreation areas. Moreover, litter vandalism and prevention can be stressed in public education programs, such as Take Pride in America, and in on-site interpretive programs.

Reduce Impacts on Heavily-Used Forest and Range Areas

On some sites, increased recreation use and steady or declining funds for management have resulted in significant resource damage. When damage occurs, the area's carrying capacity has been exceeded. However, while some areas suffer heavy use, often other nearby

Protecting natural beauty may be one of the most important opportunities for resource management in coming decades.

areas offering the same kinds of outdoor opportunities are relatively lightly used. A major opportunity exists to redistribute use to less intensively used and possibly less ecologically sensitive areas, thus avoiding or lessening damage from overuse.

Improve Maintenance of Facilities

Because of previous funding shortfalls, a backlog of needed maintenance and restoration of facilities has been growing at federal, state, and local recreation areas. Failure to perform routine or cyclical maintenance can allow facilities to deteriorate beyond restoration or repair, representing a loss of the public's investment. Moreover, poorly maintained or unsafe facilities reduce visitors' enjoyment and can actually deter use, thus effectively reducing recreation supply. Protecting past investments in expensive facilities, increasing visitor enjoyment and safety, and expanding supply can be accomplished, in part, by eliminating maintenance backlogs.

Protect Historic and Prehistoric Areas

Visiting historic and prehistoric sites is a popula outdoor activity, and it is projected to grow even larger In 1987, some 32% of the recreating public visited a his toric or prehistoric site at least once. Many of these site are managed by recreation-related public agencies Federally protected resources range from Dinosau National Monument, to Indian cave dwellings, to numer ous Revolutionary and Civil War battlefields. States alsc protect important prehistoric and historic resources sucl as the Gold Museum in Dahlonega, Georgia. Private organizations also maintain significant historic sites such as George Washington's Mount Vernon anc Thomas Jefferson's Monticello. Whatever the managing agency or organization, these areas should be guarded from deterioration and erosion, vandalism, theft, overuse, and neglect. In addition to already identified significant prehistoric and historic sites, many currently unprotected sites need to be identified, evaluated, preserved, and made accessible.

Improve Air and Water Quality and Maintain Ecosystem Diversity

While considerable progress has been made in cleaning up the environment, most clean-up efforts have solved only the traditional and more simple problems. Difficult and pervasive problems such as the disposal of toxins and the loss of biological diversity still plague the integrity and health of natural resources. Clean and esthetic environs are the basis of enjoyment of many outdoor recreation activities and of maintaining the integrity of wilderness.

Water quality.—Major improvements in the quality of the nation's waters have made numerous streams and lakes once again suitable for outdoor recreation. The Potomac River near Washington, D.C., is a prime example. Closed to fishing and water-contact activities in the 1970's, the Potomac is now enjoyed by windsurfers, water skiers, and fishers. While significant advances have been made in reducing levels of fecal coliform bacteria and increasing dissolved oxygen, surface water and groundwater are becoming increasingly polluted by contaminants such as chlorides, nitrates, and some toxic metals (Conservation Foundation 1987). Numerous opportunities exist to increase the attractiveness of streams and lakes for outdoor recreation and to reduce the possible hazards to the health of those who use them. Growth projections of water activities have assumed continued increases in water quality. Much greater shortages of trip opportunities will occur if water quality declines.

Air quality.—While considerable progress has been made in reducing ambient concentrations of all five major air pollutants (suspended particulates, sulfur dioxide, nitrogen dioxide, carbon monoxide, and organic compounds), many areas still experience periods of poor air quality. As of 1984, some 368 air quality control regions with a total population of about 80 million people failed to meet health-based ozone standards (Conservation Foundation 1987). Acid deposition—chemicals emitted into the air which then fall to earth—are believed to be affecting forest ecosystems in some parts of the country. Many experts also express concern that increasing levels of carbon dioxide and trace gases in the atmosphere are changing the earth's climate, which could ultimately affect the distribution and vitality of forest in the United States (Shands and Hoffman 1987). Projected increases in sightseeing and other activities dependent on views and vistas are heavily dependent on air quality improvements.

Ecosystem diversity.—The loss of ecosystem and genetic diversity is a growing concern (Norse 1986). Opportunities exist to preserve a cross section of different ecosystems and to enhance genetic diversity through greater attention to protecting diversity on public lands. Private lands with important ecosystems and gene pools could be exchanged for less significant federal lands or purchased outright. Ecologically significant areas also could be incorporated into state wilderness or natural area systems or be protected by local or private action, although this is likely to involve relatively small areas. Particularly important is the preservation of prairie and grassland ecosystems. Protection of ecosystem diversity could be made an explicit purpose of federal wilderness.

Manage Whole Ecosystems

Historically, nearly all recreation lands were designated according to political boundaries rather than boundaries related to ecosystems. Often two or more public agencies or a private concern may manage portions of a single watershed, each having different management objectives. Two or more agencies might manage different habitats used by a single big game species. People are increasingly recognizing the importance of managing entire ecosystems, although political divisions make this difficult. Management by ecosystem could provide more consistent management across naturally occurring wildlife habitats and ranges, habitats of rare or endangered species, and entire watersheds. Since many recreation areas border either Canada or Mexico, some international cooperation for ecosystem management may eventually be desirable. Perhaps the best current example is U.S.-Canadian cooperation in managing Waterton-Glacier International Peace Park.

Improve Services to the Public

More and Better Information

To take advantage of opportunities for outdoor recreation, the public must know what is available. This requires broad-based information on both public and private opportunities. Often, potential users are simply not aware of the opportunities that exist. Better information availability will require imaginative efforts to develop easily understood informational brochures and other media and to get the information to potential users. Public awareness of existing outdoor recreation sites and opportunities can be increased through information and marketing campaigns that use national, regional, and local news media and recreation and tourism publications issued by public agencies and private industry. Some public agencies have enjoyed success with "user-friendly" computer terminals in public places and centralized information centers that provide information on opportunities offered by local, state, and federal agencies, local chambers of commerce, and private businesses. Expanded programs of visitor information, including onsite interpretive and educational services, could help match current and potential users with recreational opportunities in a particular area. At the same time, these types of programs can inform visitors of resource management policies and suggest appropriate outdoor behavior.

In many cases, neither the public nor many recreation site managers are aware of technical innovations in recreation activities, equipment, site development, and management techniques. To meet this need, showcase recreation areas might be established in or near populous

areas to demonstrate and publicize new and emerging outdoor opportunities and innovative management practices.

Provide Opportunities for Those Who Do Not Participate

Some people do not engage in outdoor activities at all or do so far less than other segments of society. In some cases, it is a matter of choice; but, for the elderly, disabled, poor, and some ethnic minorities, significant obstacles prevent their participation. While the reasons for nonparticipation have not been well identified or documented, it should be possible to increase participation across the social spectrum by reducing known barriers and making outdoor recreation more appealing. For example, if low incomes mean that some people cannot afford to pay for transportation to distant recreation sites, then parks and playgrounds can be developed closer to where they live and shuttle services can be provided. If this is not feasible, then subsidized transportation to distant recreation areas could be considered. For the mentally or physically disabled, opportunities exist to build special facilities to permit their enjoyment of the outdoors and provide information on opportunities available. Disabled persons generally have the same needs as all others; usually, the problem lies with inaccessibility or hazards.

Anticipate Changes in Public Needs

The public's recreational activities are undergoing constant and rapid change. Managers of public lands are challenged to accommodate the resulting new demands—from campground hookups for large, self-contained recreation vehicles to cliff access for hang gliders. The bicycle is a good example of equipment evolution and public tastes in outdoor recreation. In 1960, a bicycle was a heavy, balloon-tired machine built for use

Access to ocean shorelines and natural areas will represent some of the greatest opportunities to improve recreation supply in the future.

n smooth, flat surfaces. Today, there are many different inds of bicycles—touring, racing, BMX, and the mountain bike made for trail riding. Bicycling is no longer an ctivity limited to smooth paved surfaces. To take maxinum advantage of new technologies, the public requires ccess, information, services, and facilities. The public and manager is called upon to provide opportunities for raditional and popular activities such as camping and iiking while accommodating new activities such as nountain and BMX biking. The recreation manager must lso be sensitive to demographic changes that affect ecreational use patterns such as population growth or lecline, increased numbers of immigrants, the rising umber of single-parent and female-headed households, nd increased numbers of foreign visitors. Establishing nodel recreation sites in different parts of the country, ystematically monitored to identify changes in patterns f recreational use, could provide information that would ielp managers anticipate and accommodate changing ublic recreation demands. Strong, on-going programs f research to monitor public tastes and attitude changes vould provide baseline information and enable anticiation of change.

ducate the Public About Natural Resources

Outdoor recreation offers an opportunity for the pubic to better learn about the role and importance of natural ystems and their conservation and wise use. This beneit may be realized in addition to the benefits of outdoor ecreation as an activity simply to be enjoyed. A growng public interest in wildlife observation, visiting hisoric and prehistoric sites, and nature study points to the otential of public education programs. Such programs, including interpretation integrated into recreation activities, might well help reduce vandalism and destruction of trees and wildlife in public recreation areas and make restrictions on use for resource protection more acceptable to the public or even less necessary. Interagency cooperation and partnerships with nonprofit organizations can expand and enhance educational and interpretive programs. On the Chippewa National Forest in Minnesota, for example, the National Audubon Society offers a training program for naturalists working at area resorts. In future years, as the American people may become yet more detached from natural resources, outdoor recreation may become the primary vehicle to achieve environmental awareness and sensitivity.

Expand Coordination, Cooperation, and Partnerships

Many organizations and private businesses provide or are associated with forest- and range-based outdoor recreation. They include federal, state, and local agencies and quasi-public or private organizations such as the Appalachian Mountain Club, the Boy and Girl Scouts of America, YMCA's, and the Izaak Walton League of America. Many opportunities also are offered by churches, civic clubs, and neighborhood associations. Numerous commercial organizations, from Kampgrounds of America to wilderness outfitters, provide or facilitate outdoor recreation. These agencies and organizations may provide competing or complementary outdoor recreation opportunities. In an era of tight government budgets and growing private investment, improved coordination among public agencies and private sector organizations can increase recreational opportunities cost-effectively

Providing learning experiences may become one of the most important management activities.

by avoiding duplication of efforts, by more comprehensively identifying needs, by pooling resources, and by exchanging information on effective and ineffective programs. Through working together, the needs of many organizations and users can be met simultaneously and more cost-effectively than if each worked separately. Outdoor recreation research and technology transfer is a particularly fertile area for cooperation. For example, the production of the analysis for this Outdoor Recreation and Wilderness Assessment involved more than a score of public agencies, universities, private organizations, and individuals.

Considerable opportunities exist to improve recreation resources and services by cooperation among government agencies. Various federal and state land-management agencies often have adjacent lands. By coordinated efforts, these agencies can supply a more diverse range of complementary recreation opportunities while maintaining each of their separate management philosophies.

Government and private organizations and businesses have a long history of cooperation in providing public outdoor recreation. Private entrepreneurs manage ski areas on many national forests, and concessionaires provide food and lodging in many national parks. Nonprofit organizations work with federal and state agencies to provide interpretive publications and programs at recreation sites. The Appalachian Mountain Club and numerous other volunteer groups help maintain trails. While public-private partnerships are growing in number, the potential has barely been tapped. Opportunities to bring public agencies and the private sector closer together in short-term, goal-specific associations, or long-term, more comprehensive relationships, are nearly infinite. Cooperation and partnerships can also serve to build coalitions for the support of federal, state, local, and private outdoor recreation programs and open space preservation.

Opportunities to Increase Supply of Wilderness

The NWPS currently contains about 89 million acres of federal land, about 4% of the nation's total area. About two-thirds of the wilderness acreage is located in Alaska; only 5% is east of the Great Plains. Potential growth of the Wilderness System depends upon additions from federal lands already under study, federal lands which, to date, have not been considered, and other state, local, and private lands with wilderness character. Such opportunities exist.

Complete Existing Wilderness Studies

In excess of 50 million acres of Forest Service, National Park Service, Fish and Wildlife Service, and Bureau of Land Management lands are being studied for their wilderness suitability. Where lands possess wilderness potential, they present an opportunity for inclusion into the System. Large, intact, or nearly intact ecosystems, such as the Greater Yellowstone, California Desert, Appalachian Mountains, and Arctic Slope, are major opportunities. Nonrecreational values should be conside
equally in determining suitability.

Study Alternative Wilderness Types and Location

Other lands now managed by the Department of
fense and Bureau of Indian Affairs could also be
mined for wilderness potential. Territories and ot
possessions of the United States could be examined
areas having high value for designation, particularl
protecting ecosystem diversity.

In addition to traditional federal surface lands, ot
types of significant resources and ecosystems provide
portunities for wilderness or wilderness-like values,
cluding caves, freshwater lakes, coral reefs, kelp fore
and ocean coastlines.

Not all lands and waters with high wilderness val
are owned by the federal government. Where such la
are owned by states, local governments, or private org
izations, efforts should be made to find means
protection.

Opportunities to Maintain Existing Quality of Wilderness

Designation of wilderness does not necessarily ens
that these lands will forever maintain a wilderness ch
acter. Public use may transfer some human influen
such as air pollution to wilderness areas. Even so, so
opportunities are available to help maintain the qual
of wilderness.

Improve Wilderness Education

By definition, only humans have the capacity to
versely impact wilderness character. Wilderness visit
particularly recreational users, can be educated in lo
impact procedures as one means to help reduce unnec
sary or undesirable impacts. Such efforts may util
interpretive programs and techniques at the point
entrance into a wilderness, as well as through outrea
programs to educate communities through schools
other institutions.

Improve Wilderness Management

Resource managers have the prime responsibility in t
protection of wilderness values and resources. Mana
ment effectiveness can be increased through addition
staffing, training, and career opportunities. Wildern
managers are needed at each forest, park, wildlife refu
or public land district having wilderness manageme
responsibilities. Additional training and academic cou
work would be useful for these positions.

Complete Management Plans for Wilderness

Separate management plans should be completed f
each wilderness. Each plan may consider the general a

pecific values for which the wilderness was designated nd develop strategies to ensure that those values are reserved. Plans should include some type of process or establishing measurable standards for desirable conitions, such as the "limits of acceptable change" rocess.

onduct Wilderness Threats Assessment

Because of real possibilities that wilderness character nay be compromised, a separate assessment of current nd potential threats to areas in the NWPS should be unertaken. This assessment should look at both internal nd external threats. Inside of wilderness, issues that hould be examined include recreational impacts such s water pollution, erosion, wildlife disturbance, introuction of nonnative species of plants and animals, and isitor experience preferences. Outside of wilderness, hreats such as residential, commercial, and industrial evelopment along wilderness borders should be invesigated. In addition, some threats which may originate ome distance from a wilderness area, such as acid rain, ir pollution, and global climatic change, also need to e examined. These threats need to be monitored ontinuously.

ontinue Wilderness Research

A wilderness research program should continue to ocus on recreational user impacts and experiences and he extent, value, and compatibility of various nonrecreational uses. Information on research and baseline enironmental conditions within each wilderness should lso be available in a centralized computer database. Increased research and educational efforts could help both he public and wilderness managers to understand the xtent, value, and management of nonrecreational uses.

Opportunities to Improve Management for Nonrecreational Values of Wilderness

Nonrecreational values of wilderness, including cosystem preservation, plus scientific, cultural, historic, ducational, esthetic, and spiritual benefits, are as imortant as recreational uses. These wilderness values and ses may be enhanced through management and policy irection as well as through research.

Future wilderness management plans should clearly pecify all special nonrecreational values which wilderness areas provide. This direction should be translated nto guides, handbooks, and specific management practices to ensure that the intent of the legislation is realized.

Improve the Technical and Information Base for Recreation and Wilderness Management

Research provides opportunities to improve management for the outdoor recreation and wilderness uses and values discussed thus far. While substantial research has been done on the social importance of recreation, recreation demand, and topics related to near-term planning and management, gaps remain in our knowledge. For example, recreation supply and the cost of providing outdoor recreation have been inadequately researched. Moreover, research findings do not fully describe interactions among users, resources, and management. Existing wildernesses are little utilized for research aimed at monitoring changes in the environment or for understanding relatively undisturbed natural ecosystems over time. Some specific opportunities to improve our knowledge base are discussed below.

Standardized data.—If managers are to respond in a timely fashion to changes in public recreation needs or changing resource conditions, better information will be required on environmental and participation trends, likely future demand, preferences and satisfactions, and available supplies of outdoor recreation. The provision of relevant and timely information can be greatly enhanced through improved standards and definitions for recreational data. Different public and private agencies often have different and sometimes incompatible definitions for measures of recreation demand or supply. Different federal agencies may also have different monitoring and measurement standards for wilderness. Development and use of widely accepted concepts and definitions can lead to better communications and more optimal decisions and cooperation among the wide range of recreation and wilderness management interests.

Improvement of assessment methods.—Research can improve the methods for conducting future assessments of natural resources in both urban and wild environments and on both public and private lands. Managers need to better understand recreation trends so they can stay in step with change. Important areas of inquiry include how public opportunities and those provided by the private sector complement one another, better measures of recreation suitability and quality, improved knowledge of motivations, barriers to and norms of recreation participation, and a better understanding of social and economic benefits derived from outdoor recreation and wilderness.

Estimating recreation benefits.—Because social and environmental benefits of outdoor recreation are often difficult to assess, recreation and resource protection programs may be valued incorrectly, if at all. Without hard dollar values of the benefits accruing from outdoor recreation, land managers find it difficult to justify investments in recreation programs and facilities. Researchers have made substantial progress in estimating commensurate values for outdoor recreation. By improving valuation technology and models, the benefits of outdoor recreation programs can be documented and brought to bear on resource allocation decisions. In the same way, nonrecreational uses and values of wilderness are often undervalued, and sometimes not even recognized, in the forest planning process. Basic and applied research should document these nonrecreational uses so they can be weighed with values such as timber, water, forage, and mining.

CHAPTER VII: OBSTACLES TO IMPROVING OUTDOOR RECREATION AND WILDERNESS RESOURCES

Numerous and significant obstacles may impede achieving improvements of potential recreation opportunities and wilderness resource management identified in the previous chapter. These identified constraints typically cut across several opportunity categories. For example, liability for personal injury inhibits opening of private land for public use and also deters some uses of public lands. Imperfect information on recreation and wilderness demand and supply, participation, preferences, barriers to participation, and the effectiveness of opportunities constrain the responsiveness of planning to a variety of new demands and changes. Constraints fall into five broad categories:

1. Distribution of recreation lands relative to urban areas and public access;
2. Funding;
3. Liability;
4. Information and education for both users and managers;
5. Coordination and communications among providers.

Distribution of Recreation and Wilderness Lands and Obstacles to Public Access

Inadequate access to recreation lands, open space, and wilderness constrains the expansion of recreation opportunities, especially for people living in populous metropolitan areas and in the East and South. Most federal land available for outdoor recreation and wilderness is located in the West. Though federal land exists close to some metropolitan areas, the most attractive federal lands, waters, scenery, and facilities often are located some distance from urban areas. The same is generally true for state lands within the four Assessment regions. Accessibility will remain a constant issue so long as most Americans live in the East and most federal lands remain in the West. Improved access to private lands in the East could enhance some recreation opportunities.

Conversion of Private Land to Development

The conversion of available private farm, forest, and range lands to development limits opportunities for public use or public acquisition. From 1969 to 1978, some 90 million acres of farmland were converted to nonagricultural uses including residential, commercial, and industrial development plus roads, highways, and airports (Cordell et al. 1985). Agricultural and forest lands likely will continue to be developed at a rate of about 1 million acres annually for the next 5 decades (USDA FS 1987). This will significantly reduce the total private land base available for public recreation. The situation is more acute in the East and South where private lands constitute the majority of the land base. The loss of potential recreation lands has long-term implications for management of public recreation areas. More users forced on a smaller land base will increase the potential for conflict among users and for overuse of available recreation areas.

Closure of Private Lands to Public Access

The increasing trend toward closure of private land to general public use also limits the expansion of outdoor recreation opportunities (Wright et al. 1989). People often purchase rural land as a personal recreation site and post it against public use. More landowners are leasing land to private groups, particularly for hunting, and excluding the general public.

In addition, there is a trend toward increased numbers of farms less than 50 acres, forest tracts less than 100 acres, and tracts of more than 500 acres. Large tracts are often better suited for exclusive lease arrangements, while owners of small tracts generally want to reserve their land for their personal use and are less inclined to permit public recreation. This situation especially affects recreation in the East. Even private industrial lands once open to the public are being closed or restricted.

Closure of private land can block access to public lands, lakes, streams, rivers, and beaches. Such closures are a major problem for western national forests and BLM lands. In the East, private land closure stimulated public acquisition of the Appalachian trail corridor.

Closing private lands seriously restricts options to direct different user groups to the most appropriate land ownerships. It also diminishes close-to-home recreation opportunities, and it provides no relief from negative impacts incurred at heavily used public areas. Opportunities to forge partnerships among private landowners, users, and public agencies also may be diminished.

Poor Access to Recreation Lands by Special Populations

Disadvantaged people often do not, or cannot, visit distant national parks and wilderness areas. The cost of travel may be prohibitive (Hultsman et al. 1986). Physically disabled people often need special transportation or facilities which cannot be found in many outdoor recreation settings. Research indicates that resource managers seldom encourage disabled people to participate in outdoor activities and seldom respond to special needs (Hartmann and Walker 1989).

Conversion of Wilderness and Potential Wilderness Lands

Development and activities around some wilderness areas, especially adjacent road construction, timber harvesting, mining, oil and gas extraction, and commercial

Inadequate access to recreation lands will be an important constraint to improving outdoor recreation supply in the future.

and residential development, have effectively reduced the acreage of areas having the true wilderness character of vastness and wildness. Such activities may affect opportunities for primitive recreational experiences and solitude. Additionally, wilderness wildlife habitats and populations may be affected and fisheries and water quality, cultural resources, visual quality, and scientific uses may be compromised (Chestnut and Rowe 1983, Schonewald-Cox and Stohlgren 1989, Wilderness Society 1989). Policies discouraging buffer zones surrounding critical wilderness areas permit many of these effects to occur virtually up to the boundaries. These lands will have little, if any, chance of regaining wilderness character in the foreseeable future.

Wilderness solitude and biotic diversity also may be lost through the effects of sources not restricted by boundaries. Sights and noise of aircraft, particularly military overflights, adversely affect wilderness characteristics of solitude (Peine et al. 1989). Other areas have been degraded by the effects of air pollution on vegetation (Peine et al. 1989) and visual quality (Chestnut and Rowe 1983). Perhaps the greatest threat to loss of effective wilderness areas may come from atmospheric changes, including global warming, desertification, and ozone depletion (Peine et al. 1989).

Funding

Funding obviously affects resource management. Small budgets delay program expansion, land acquisition, development of informational and educational materials, and research.

In recent years, federal and state funding for outdoor recreation and wilderness has been declining. It is significant that in their reports to the President's Commission on Americans Outdoors, 48 states expressed a need for stable funding, the most frequently mentioned concern. The Domestic Policy Council (1988) concluded that public budgets have difficulty sustaining on a regular annual basis the outdoor recreation services, maintenance, and facility replacement needs on public lands. As a result, it is difficult for public agencies to supply the quantity and quality of opportunities demanded by consumers on an even or expanding annual basis. This is the experience at both federal and state recreation sites.

Funding declines and instability reduce ability to maintain, much less expand, recreation and wilderness resources, programs, and research. Opportunities to preserve and protect exceptional natural features or significant historic or cultural sites can be lost because of insufficient funding. Likewise, opportunities to educate

visitors through on-site interpretive and educational programs can be limited. If the downward budget trend of recent years were to continue, managers will not be able to respond to changing demands on resources. Only recently have some agencies been given authority to charge or increase user fees or to develop other methods to raise funds for operations and maintenance (Driver et al. 1985).

Generally, federal and state authority to charge fees is limited. All seven federal land management agencies may charge fees for use of specialized sites, facilities, equipment, or services furnished at federal expense (Domestic Policy Council 1988). However, fees are limited and may be collected only for areas that meet established standards of development. The National Park Service is the only agency authorized to charge entrance fees, although Congress has barred charges at some units and has limited the amount that can be charged. In the case of state recreation areas, state legislatures often specify the areas where fees can be charged. Moreover, legislatures generally establish uniform, system-wide charges that preclude differential fees to better distribute use or recoup high management costs. Only recently have federal fees been returned to the collecting agency rather than put in the general treasury (Driver et al. 1985). Surveys of recreationists have indicated that they are willing to pay fees or accept higher fees for use of public outdoor recreation areas if the revenues are earmarked to support or improve the services and facilities where they were collected (Domestic Policy Council 1988).

Some recreation agencies have been successful at attracting contributions of equipment, funds, and labor for facilities and habitat improvement projects. However, adequate base funding is essential to assure that there are facilities and resources to satisfy the broad range of public demands.

Tort Liability and Increased Costs of Insurance

Substantial increases in the cost of liability insurance have significantly reduced outdoor recreation opportunities. The PCAO (1987) cited specific examples: play equipment was removed from city playgrounds; a recreation department stopped renting and converting old houses into recreation centers; and sledding was barred in city parks. Increased willingness to sue, higher awards for injuries, as well as sovereign immunity have all stimulated a dramatic increase in the number of recreation-related lawsuits (Hronek 1985). Meanwhile, juries appear to give less weight to traditional defenses of voluntary assumption of risk and contributory negligence.

Some public agencies have curtailed programs to reduce their vulnerability to tort liability actions, but the liability issue has most acutely affected private providers. Ski resorts, outfitters, and river guides have had to increase their fees substantially. Private landowners frequently cite a fear of being sued as a major factor in deciding to close their land to public use. Liability can also affect decisions about charging fees for use of both private and public lands. Where fees are charged, the public agencies and private landowners may be held to a higher standard of public protection than if no fee is levied (Koslowski 1989). Increased insurance premiums and greater risk of lawsuits may more than offset revenues from fees.

In response, 48 states have enacted recreational use statutes intended to provide some protection for private landowners who permit public use of their land (Koslowski 1989). Even so, the threat of liability continues to inhibit opportunities to expand recreational opportunities offered by both public agencies and the private sector.

Providing sufficient opportunities for camping, family gatherings, and other developed site uses may be a challenge if agency budget trends continue.

When faced with a potential liability, agencies most often restrict use or close recreation areas.

Information and Education for Users and Managers

Incomplete information about users also often constrains the provision of outdoor recreation and wilderness opportunities. Without complete information on who the customer is, what his or her preferences are, and barriers to his or her participation, policy makers and managers are less able to develop effective programs. Likewise, the absence of complete information on outdoor recreation opportunities hampers efforts to increase supplies and can result in wasteful overlaps. Absence of information about opportunities also reduces supply because sites and facilities unknown to the public, in effect, do not represent an opportunity. Failure to develop new management techniques and to transfer management technologies may inhibit management performance. For example, managers could benefit from information on new techniques to avoid user conflicts and ways to prevent or mitigate adverse impacts to forest, range, and wilderness resources.

Coordination and Communications Among Providers

Seven federal agencies manage recreation lands, four manage wilderness, and each has its own land management philosophy, mission, and objectives. Another 60 federal agencies provide directly or indirectly some recreational programs or services (Shivers 1987). Moreover, each of the 50 states has agencies that manage state lands and programs to provide recreation or some form of wilderness-like area (Soper and Humke 1989). More than 3 million acres of wilderness-like areas are also maintained in land trusts by nongovernmental organizations such as The Nature Conservancy. Poor coordination and communications among public outdoor recreation providers and between public agencies and private interests can constrain outdoor opportunities. The Domestic Policy Council (1988) found that assessing the adequacy of outdoor recreation supplied on federal lands is complicated by geographic, organizational, and functional fragmentation of the involved agencies. Further, the absence of any clear, integrated national policy guidance hinders recreational development.

While some federal lands managed by different agencies may be contiguous or in close proximity, regional or area coordination is often lacking. Potential interagency relationships include situations such as a national forest which attracts visitors who hike backcountry trails in the forest, but who then camp in a nearby state park. The Domestic Policy Council (1988) asserted that, "An integrated federal policy relating to area and regional coordination and development of recreation on federal lands could improve effectiveness and efficiency for both national and local purposes [and] assure similar coordination at the higher levels of agency coordination."

Inadequate coordination among government levels and between government and private organizations can ultimately cause management duplication and deficiency. The degree of cooperation, in part, determines how well

public lands meet the outdoor recreation and wilderness demands of the American public.

Management of the recreational and nonrecreational values and benefits of wilderness also is hampered by a lack of interagency cooperation. For example, where animal and plant communities do not follow political boundaries or where esthetic and spiritual values may be attached to very large areas, close coordination in management is essential. Inadequate or imprecise direction, starting from the language of designation acts through the diverse policies of the managing agencies, also presents an obstacle to consistent management of wilderness.

CHAPTER VIII: OUTDOOR RECREATION AND WILDERNESS PROGRAM IMPLICATIONS

The findings of this Assessment of the Outdoor Recreation and Wilderness Situation in the United States show that demands for outdoor recreation and wilderness opportunities will continue to grow and diversify. But, unless opportunities for some activities are expanded more rapidly than in the recent past, significant shortages will affect many popular recreation activities and wilderness uses, especially for the people living in the East and near urban areas. The two major management options are maintaining the current pace of providing recreation opportunities or expanding opportunities rapidly enough to prevent the projected shortages. Either will be expensive since both require large operating, acquisition, and capital budgets.

Regardless of annual budgets and expenditures, the American public will increase its outdoor recreation. People will be taking fewer long trips, but more short trips; and, many urban residents will continue to be limited in how far they can travel for recreation. As a consequence, land and water facilities near urban centers will be even more heavily used. Unless new resources and facilities which can disperse use are built and existing resources and facilities are carefully maintained, resource agencies may be unable to accommodate the growing demand for outdoor recreation. The more significant questions become not only which major option costs more and which less, but also which option confers the greater total benefits on individuals and society.

This chapter is devoted primarily to identifying the implications of the findings of this Assessment for shaping the Forest Service's management, research, and assistance programs for the 1990's. These implications will be used as one of the considerations for development of alternative program strategies for the agency.

Implications for Management of the National Forests

Many national forests could accommodate higher levels of recreational use than they now support. A few forests could accommodate increased use with little more than continuing current management and development strategies and making the public more aware of the opportunities that exist. For most forests, accelerated investments in management, access, and facilities would be required. This would include eliminating present maintenance backlogs, increasing efforts to stimulate public awareness and assure safety, and providing high-quality outdoor opportunities for both foreign and domestic visitors. While accommodating more use, managers will be challenged to protect national forest resources from overuse. Management, resource, access, and facility needs are likely to be most intense in the East where effective recreation opportunity is least, where crowding is greatest, and where predicted closures of additional private lands will have the greatest impacts. Because many national forest lands are quite remote, increased visitation may not occur in those areas even with better information and management. On the other hand, forests near urban areas should experience large increases in visitation, whether or not more information or management is provided.

Existing land management plans for individual national forests should serve to identify outdoor recreation

Increasingly, public lands are looked to as a place for recreation.

opportunities, partnerships for delivering those opportunities, and the markets for recreation. Collectively, national forests possess a broad diversity of recreation opportunity. This diversity hinges on the unique and distinctive character of individual forests. A key management strategy will be to inform the public about national forest opportunities while directing specific user groups to those national forest resources with the most potential to meet their particular recreation demands with the least conflict among users. National forests, national grasslands, and their components, such as wilderness areas, must be planned and managed as both individually unique units and as parts of a larger system.

Serving Urban and Special Populations

The steadily increasing use of national forests by urban population groups will challenge managers several ways. They will be expected to provide for the physically active as well as the physically or mentally disabled while protecting resources from potential damage caused by overuse. This is especially critical in wilderness. Where appropriate, important managerial actions include: (1) upgrading of arterial roads for sightseeing and pleasure driving; (2) construction of additional roadside rest areas, vistas, and access to historic and prehistoric sites; (3) improved facilities for family gatherings, educational exhibits and programs, and picnicking and camping sites; (4) improved loop trails suitable for viewing wildlife, nature and wildlife photography, collecting berries and for strolling; and (5) improved information and signing. All of these must be accomplished with special disadvantaged populations in mind. Existing trails, buildings, and parking areas may require structural modifications and new facilities with updated and appropriate design considerations must be built.

Even though many urban residents increasingly s adventure and risk-oriented recreation and are going c doors to find it, the continuing urbanization of American population means people are becoming m detached from natural environments. In contrast to g erations past, a land ethic is, very likely, not a part of m people's heritage. An aggressive community outrea program to offer environmental education and outd skills training could become an essential managem tool. Better prepared recreationists create fewer saf problems, and better educated recreationists cause l damage to the resources they enjoy. On-site interpret programs can reinforce the outreach programs. To be fective, these actions must be strengthened with adequa staffing. Ultimately, nothing can substitute for know edgeable, host-oriented uniformed personnel in the fiel

Forest Environments Requiring Attention

Increased management and access will be required improve opportunities on undeveloped areas near roa and on partially-developed roaded areas. These are th outdoor environments where the greatest declines in o portunities are projected, as much as 40% within th next 50 years. Should these projections prove true, suc lands near urban areas would become especially impo tant. The increasing incidence of private land leasin and closures could also contribute to blocking essenti access to public lands. Providing guaranteed access t undeveloped and semideveloped national forest land will be a major challenge. And, as more people use thes lands, managers will be further challenged to prote them from overuse. Hunters, backpackers, wildlife ob servers, and sightseers all pressure the resources o which their recreation depends. If present trends con tinue, eventual shortages can result in overcrowding

Providing convenient opportunities to photograph and study natural settings will be an important strategy for managing National Forests in coming years.

user conflicts, and resource degradation. Improving access is essential to prevention of these consequences of projected opportunity shortages.

The demand for cross-country skiing and similar dispersed winter activities is expected to far exceed supply over the next 5 decades. To meet projected shortages, more attention should be devoted to increasing cross-country ski opportunities in climatically suitable forests that receive enough snow for this type of activity. Access to private land will be one of the keys. Also, downhill skiing facilities must continue to expand and new facilities must be built. The prediction of no shortage in downhill ski opportunities is based on the assumption that recent trends in ski area development can and will continue. The Forest Service is the largest supplier of downhill ski opportunities, and its actions regarding this resource will determine whether or not a shortage will occur.

If the recent emphasis on providing water opportunities is continued, no major shortages are projected for most water-oriented activities. But, the expected growth in such activities as white-water rafting, canoeing, kayaking, and swimming will require maintenance of access and control of erosion and pollution that could impair the quality of water resources within the national forests.

Acquisition of Land and Easements

While no massive land acquisition program seems likely in the near future, it may be necessary and feasible to purchase land or easements to permit public access to some areas of the national forests. In some cases, especially in the East, it may be desirable to acquire lands which provide exceptional scenery or outdoor opportunities, link existing recreation areas, or preserve the quality of the recreation resources on existing public lands. Developing partnerships with nonprofit organizations to acquire desired lands could be a cost-effective way to accomplish management goals. The exchange of disjunct parcels of national forest lands for private lands could be a cost-effective way of increasing opportunities. While opportunity is still available, unique and significant areas important to outdoor recreation and wilderness should be identified and protected. These areas may include wilderness-like areas, unique natural features, travel corridors, and significant scenic, historic, and archaeological sites.

Quality of Resources and Facilities

Meeting projected increased demands for outdoor recreation will require attention to the quality of resources and facilities on the national forests, especially in the East. The scenic quality of national forests is highly valued by the public and has led to creation of a scenic byways program. Relatively large gaps between demand and supply are projected for scenery-oriented activities such as pleasure driving, sightseeing, and nature photography. To avoid degrading the view from well-traveled roads, hiking trails, or rivers, and to minimize erosion and stream sedimentation, facilities, forest roads, and timber sales should be carefully planned and executed. Addressing maintenance and rehabilitation backlogs must be continued and accelerated to avoid excessive and costly deterioration of facilities. Such acceleration could require a substantial, though short-term, funding base. Some new visitor centers, picnic areas, campgrounds, road access, trailhead parking, and trails will be needed to meet anticipated visitation growth and to avoid damage from overuse.

User Information and Education

National forests receive the greatest visitation of all federal lands; but, many people, particularly urban dwellers, are unaware of the opportunities they offer. More rigorous and diversified exposure could help the public realize the outdoor recreation potentials of national forests. Off-site information targeted to urban publics, with attention to various ethnic groups, the economically disadvantaged, and persons with physical and mental disabilities, could greatly improve their opportunities for participation in outdoor recreation. On-site information and interpretive services could help visitors better appreciate their outdoor experience and treat resources with greater sensitivity. Improved information for visitors can help prevent overcrowding and overuse by directing visitors to less crowded wilderness and non-wilderness areas and by informing them of the impacts they have on soil, water, flora, and fauna. Such information would need to be sensitive to the different backgrounds of each group.

Dissemination of information to potential visitors could be made more effective through expanded cooperation within divisions of the Forest Service, through increased research on information dissemination techniques and effects, and through greater partnerships with other federal, state, and local agencies and with private cooperators. Consolidated information centers, cooperative publications, and innovative dissemination methods could make it more convenient and enjoyable for the public to learn about outdoor opportunities on national forests in their area and across the nation.

Establishing Partnerships

Much of the needed work—from facilities construction and management to interpretation—could be accomplished through partnerships involving both profit and nonprofit organizations within the private sector. Currently, the Forest Service utilizes the private sector to provide services and to build and maintain facilities and trails. Efforts could be intensified to include guide and outfitting services for backcountry and wilderness use, backpacking, trail riding, and cross-country winter sports. Specific means for establishing partnerships include: (1) communicating with private landowners

about the existing incentives, income potential, and social values of opening or keeping open their lands; (2) providing incentives for private investment to stimulate a greater variety of recreation opportunities, especially in economically depressed rural areas; (3) using land management plans to determine forest-specific recreation opportunities and to emphasize local opportunities for partnerships; and (4) providing incentives for national forest permittees, outfitters, guides and other concessionaires to provide recreation opportunities for the disabled and disadvantaged. As was shown in chapter I, membership and purchasing ability of both conservation-oriented and nonprofit organizations, such as The Nature Conservancy, and special interest groups, such as the American Hiking Society, are expected to grow. These organizations could be approached with specific plans for facility development, land purchases, or other projects to the benefit of both the organization and to other users of the National Forest System. Developing partnerships with elementary and secondary schools and local nature centers could increase the environmental and recreational awareness of students and the community and is an especially inviting opportunity. The increasing number and diversity of local government parks and recreation departments also offers great potential for making available environmental and recreational information.

Charging or Increasing Fees for Use of the National Forests

Implementing new fees where none have been previously charged or increasing existing fees could help cover some management costs of especially costly developed facilities. Moreover, a graduated system of fees related to use pressures for campgrounds could help limit over crowding and overuse of the more popular sites. Additional study is needed to identify acceptable and cost-effective means for charging for dispersed recreation. Typically, the constituents of this kind of recreation are both willing and able to pay fees. The major condition for their willingness is that the revenues thus generated be used to improve and maintain those sites where the fees are collected. Recent legislation has begun a move in this direction. Sometimes, however, regular appropriations are reduced proportionate to the increased fee revenues, resulting in zero net gain.

Implications for Forest Service Research

This analysis of the recreation and wilderness situation has implied a need for research for dealing with supply and demand changes, for better understanding users and their outdoor recreation preferences, for improving management techniques, for improving measurements of recreation phenomena, and for managing new and rising noncommodity forest uses. Although important advances have been made since the last Assessment, many critically important research questions remain unresolved. Without research, decisions may be poorly based and inappropriate.

Trends in outdoor recreation demand and supply must be monitored on a continuing basis if managers are to have sufficient advance information to respond in a timely manner to changing conditions and changing public preferences. Monitoring demographic and economic trends and recreation-related technological advances is essential to improving projections of future change. Better information would also help guide outreach programs addressed to previously uninvolved publics.

Research is necessary to monitor changing public demand for national forest recreation and wilderness opportunities.

Improved data on the supply of recreation resources ıt all levels, public and private, would help eliminate werlaps, better identify gaps in opportunities, and ensure nore efficient investment of funds. As prediction capaoilities improve, so too will planning and management.

In doing this Assessment, it became clear that standırds for data collection, analysis, and presentation and oroadly-accepted definitions of supply and demand are ıeeded. Continuing the effective partnerships formed to levelop the data and analyses for this Assessment is lesirable. An example of such a partnership is that with tate recreation agencies for coordinating federal data ollection efforts with the states' comprehensive outdoor ecreation plans.

Research also will be needed to help managers deal vith intensified, and sometimes conflicting, public uses. pecific topics warranting research priority include:

- Managing of high-use recreation areas to help managers resolve user conflicts, to communicate effectively with users, to control vandalism, to limit environmental degradation, and to deal with other site abuses.
- Managing wilderness and other roadless sites to help managers evaluate carrying capacities and to set use standards, especially for popular areas, to better communicate with users, and to unobtrusively manage for visitor use.
- Planning, monitoring, and managing national forest wilderness for nonrecreational uses and values.
- Managing special areas, to help managers preserve cultural, historic, and prehistoric components and artifacts, control vandalism, and to interpret such areas for the public.
- The interaction of outdoor recreation with other forest and range resources and uses and the complementary roles of public and private sectors in addressing needs for public use opportunities.
- Developing low-cost techniques for constructing, restoring, and maintaining facilities and for minimizing the adverse impacts of use.
- Understanding the social disparities of the existing distribution of recreational opportunities, differences in barriers to participation among different populations, and the sources and possible solutions to achieve more balance.
- The social, economic, and environmental benefits or consequences of outdoor recreation and wilderness management and use.
- Effective information dissemination to users and potential users of Forest Service lands through marketing and interpretation.

This information would permit managers to more accurately evaluate the costs and benefits of recreation and wilderness programs and to weigh tradeoffs with other uses and values.

Technical Assistance to Private Land Owners

Private lands could provide more recreation opportunities for the public than they now do. They have the potential to help ease the uneven geographic distribution of recreation opportunity. To do so, owners need more information on management techniques and costs, earnings potential, and liability assessment. Assistance to private owners can be offered by state and local governments. Most states have agencies which provide forestry, wildlife, and conservation assistance. Many cities and towns have created parks and recreation and forestry departments with a variety of professional staff. These entities could become vital links to improving the availability of private land to the recreating public. The USDA Soil Conservation Service is responsible for providing technical assistance concerning income producing recreation on rural nonfederal lands; the Cooperative Extension Service is responsible for providing educational programs. As appropriate, the Forest Service's State and Private Forestry division could cooperate through these local, state, and federal organizations to provide information relevant to improving private lands management.

Implications for Wilderness Management

The evidence is mounting that nonrecreational uses and values of wilderness are rising relatively faster than recreational uses and values. Scientific uses, human development and spiritual growth, education, and preservation of critical wildlife, fish, and plant habitats, watersheds, and gene pools are all uses that could benefit from increased management emphasis. Guidelines are needed for coordinating management of both recreation and nonrecreation uses of wilderness areas. Forest Service research could work with the National Forest System to develop effective methods for monitoring nonrecreational uses, to quantify and describe nonrecreation demands and values, and to estimate baseline levels of nonrecreational uses of wilderness resources.

Adequate personnel must be available to monitor recreational use of wilderness, assess use impacts, and prevent abuse of fragile archaeological and ecological sites. National forest management plans should be required to include a review of all roadless areas and to recommend wilderness designation for those that would fill an ecosystem gap in the National Wilderness Preservation System (Davis 1989). Concurrent with direct management, indirect management should be implemented. Administrators and managers cannot assume the public understands the spectrum of values inherent in wilderness. Through various partnerships and outreach programs, the Forest Service can keep the public informed of wilderness values.

Recreation and Wilderness Programs Within the Context of Assessment, Program, and Policy Implications

Several general issues surround the future of the Forest Service's outdoor recreation and wilderness programs. These issues also pertain to timber, forage, and the other

forest and range land uses. The discussion that follows centers on outdoor recreation and wilderness program implications in the context of four broad questions. These four questions capture the essence of selected major forest and range resource policy issues currently being debated in general and in the Forest Service in particular.

1. What should the federal government do to ease potential shortages of outdoor recreation and wilderness opportunities?
2. What should the role of national forests be in the production of outdoor recreation opportunities and protection of wilderness?
3. Should recreation and wilderness policies for management of national forests vary among regions?
4. What role should Forest Service research programs play in the production of new information and technology needed for increased recreation opportunities?

Easing Potential Shortages of Opportunities

In this Assessment, shortages are predicted for future years if costs of opportunities do not rise and recent supply trends continue. The largest such shortages are predicted for undeveloped backcountry as well as near-road opportunities. Access to private forest and range lands, as well as public lands near populated places, are highly critical to providing sufficient opportunities. The most severe predicted shortages are for wildlife observation, day hiking, nature photography, pleasure driving, sightseeing, and similar activities. These activities depend on accessible, reasonably close, visually attractive, and relatively undisturbed natural environments. The federal government is the major holder of properties with such environments, for example, in national forests, parks, and wildlife refuges. Some of these federal properties are relatively remote and may not effectively meet future shortages. For the majority of these properties, however, the federal role is to ease future opportunity shortages by improving access to and the quality of the surrounding federal estate.

Easing potential shortages could also be accomplished, in part, by moving more toward priced admission for recreational use of federal lands. Most forms of recreation on federal lands currently require no fee. A growing acceptance of pay-as-you-go as one means for administering recreation programs may open new ways to produce modest revenues which could be used for further helping to improve access, management, and facilities.

The greatest shortages anticipated for wilderness opportunities are for nonrecreational uses. About 89 million federal acres are in the National Wilderness Preservation System as of 1988. These acres offer great potential for increasing nonrecreational uses. One way to encourage nonrecreational uses without generating user conflict is to redirect some recreational uses to the 100 million federal acres of wild, remote, but undesignated land.

Role of National Forests in Producing Outdoor Recreation Opportunities and Protecting Wilderness

National forests currently accommodate a wide range and large quantity of outdoor recreation activities and visitors. The emphasis is mostly on traditional uses, such as sightseeing, camping, and hiking. National forest campgrounds and other developed sites have tended toward the less-developed end of the facility spectrum. The Forest Service generally has sought to control new uses so as to limit possible adverse effects on the resource and on the traditional uses. This has generally been consistent with the desires of traditional forest users. However, the demands for less traditional national forest activities, such as trail biking, river rafting, and skiing are growing fast. Moreover, many people, particularly in urban areas, do not use national forests and for many different reasons. A new recreation initiative, the National Recreation Strategy, has been instituted by the Forest Service in an attempt to be more responsive to the public's outdoor recreation demands and to accommodate both nontraditional, as well as traditional, uses.

To meet the public's preferred demand for outdoor recreational opportunities, high rates of opportunity expansion (about 1% per year) will be needed for some activities. Downhill skiing capacity must expand 40% in the next 50 years to meet the predicted demand. National forests cannot offer unlimited recreational expansion because the Forest Service is a multiple use agency and must accommodate many uses. But, increased publicity about opportunities, more conveniences such as modern toilets, better signing, stores, vistas, fitness trails, educational offerings, and improved access would better meet modern recreation demands.

As has been emphasized, national forests can conserve American wilderness best by adding unique or representative ecosystems to the NWPS, by protecting designated wilderness areas from over-use, and by educating the public on the nonrecreational values of wilderness.

Variation of Policies Among Regions

National forests and other public and private lands are quite different in character, availability, and concentration between west and east. Major distinctions also exist among Forest Service regions. Wet coastal forests, for example, differ dramatically from drier interior forests, and the two environments cannot equally accommodate the same uses. Other forest uses, such as timber, grazing and wildlife habitat, also vary substantially between and within regions. The potential of these other uses to expand affects recreational opportunities.

Some national forests, particularly those mountainous forests in New England, the Appalachians, the Rockies, and the Pacific Coast, are nearer urban populations. They provide highly attractive natural settings and are very popular. Consequently, they have significantly different constituent groups than more remote forests. Such constituent groups have active interests in the future of these

forests. Resource and optimal use differences, urban proximity, and different constituency interests strongly imply that some differences in recreation and wilderness policies among and within Forest Service regions may be desirable. Different policies imply emphasizing different uses in different places. For the future and on a few forests, a need will exist to emphasize recreation, education, and public service more than commodity production. This may be especially true in the southern Appalachians and along Colorado's Front Range and in California. In economically depressed areas and for the urban poor, a waiver of fees may be advisable. In Alaska, where subsistence uses of wilderness may be essential to remote residents' way of life, some hunting and gathering may need to be continued. Overall, however, the need is for a consistent set of policies which permit flexible consideration of fees, use, and management according to regionally different demands, user preferences, and opportunity conditions.

Role of Forest Service Research

Over the years, the Forest Service has been a leader in outdoor recreation and wilderness research. For example, the President's Commission on Americans Outdoors relied heavily on information from Forest Service research. Likewise, Forest Service researchers have made highly significant contributions to theory, methodology, and management applications to recreation and wilderness resources. Many experts from state and local agencies and from many universities have worked cooperatively with Forest Service researchers in a very productive relationship.

The future roles for Forest Service research in outdoor recreation and wilderness will be even more challenging. To meet anticipated needs, research should encompass the task of defining and maintaining outdoor recreation databases cooperatively with other providers. It should also encompass theory advancement to enable better understanding of human values and behaviors and of human and natural environmental relationships. It would further need to focus on improving methods for carrying out applied works in economics, sociology, and other social and related sciences. A broad front of research activity will be needed if future growth and shortages of recreation and wilderness are to be effectively addressed. In addition to contributing research directly, one of the essential and historically significant roles that Forest Service research has played is to stimulate other agency and university research in areas of highest need. A more detailed examination of past, present, and future research was developed by Cordell (1988).

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Forest Service Regions and Assessment Regions

United States
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Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-190**

Consolidated Stand Tables and Biodiversity Data Base for Southwestern Forest Habitat Types

Esteban Muldavin, Frank Ronco, Jr., and Earl F. Aldon

Foreword

The initial descriptive phase of forest habitat type classification in the southwestern United States (Arizona, New Mexico, and southern Colorado) has been completed and published. To provide a foundation for future research into the biodiversity, structure, and dynamics of these forest communities, stand tables consolidating over 2,000 field plots, stratified by 11 different climax forest tree series, have been compiled. The data upon which the tables are based are made available in a computerized format, accessible by microcomputer. A suite of computer programs is also provided for manipulating the data base to meet individual research needs. An archive of noncomputerized information on stand structure, site productivity, soil analysis, plus descriptive materials such as photographs and maps has also been created. Both the data base (on floppy disks) and the archive are available for public use from the Rocky Mountain Forest and Range Experiment Station, 240 W. Prospect Road, Fort Collins, Colo. 80526.

To obtain the data base in electronic format, submit five 5 1/4-inch, high-density diskettes formatted for IBM PCAT compatible systems to the Station library. The data will be duplicated onto your disks, which will then be returned to you. Archived material can be viewed at the Station library.

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Consolidated Stand Tables and Biodiversity Data Base for Southwestern Forest Habitat Types

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Abstract

To provide a foundation for future research into the biodiversity, structure, and dynamics of southwestern forest communities, stand tables consolidating over 2,000 field plots, stratified by 11 different climax forest tree series, have been compiled. The data upon which the tables are based are made available in a computerized format, accessible by microcomputer. A suite of computer programs is also provided for manipulating the data base to meet individual research needs.

[1]*Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Contents

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INTRODUCTION

Forest community classifications using the habitat type concept of Daubenmire (1968) have been widely developed and implemented in the southwestern United States (Arizona, New Mexico, and southern Colorado). Layser and Schubert (1979) described eight climax forest tree series in the Southwest which formed a framework for subsequent habitat type classifications. Moir and Ludwig (1979) followed with a preliminary classification of habitat types within the spruce-fir and mixed conifer forests in Arizona and New Mexico. Also during the 1970's, Hanks et al. (1983) initiated a habitat type classification within the *Pinus ponderosa* Series in northern Arizona. In conjunction with the above work, Ronco et al.[2] prepared a comprehensive study plan for systematically developing habitat classifications for all tall coniferous forests from national forests and selected Indian Reservations in the Southwest (fig. 1). The goals of this study plan have now been met, resulting in eight published classifications that cover the entire region (table 1).

[2]*Ronco, Frank, Jr., William H. Moir, and E. Lee Fitzhugh. 1978. Forest habitat type classification for Arizona, New Mexico, and southwestern Colorado. USDA Forest Service Study Plan FS-1203.81 [Mimeo]. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.*

The completion of these classifications summarizes the initial descriptive phase of habitat type research in the Southwest and signals the next, more synthetic phase, where the focus will be on the detailed structure and dynamics of these communities. Areas of research envisioned in the synthetic phase include regional correlation studies, detailed analysis of dynamics and diversity in and among habitat types (particularly successional trends), productivity assessment, and regional floristic analysis. The habitat type classifications form the foundation for such research, but in order to do so, the quantitative and qualitative data upon which they are based must be made available. The habitat type data base is a storehouse of information about floristic diversity, environmental characteristics, stand productivity, and other descriptive information on forest communities of the Southwest. Our purpose here is to provide a comprehensive data base in an accessible and usable form for future research.

The concerted classification effort in the Southwest resulted in a large, more or less uniform data base of quantitative and qualitative information from approximately 2,000 field plots established during the development of the classifications. We are making available the actual plot data in a computerized format that is accessible with an IBM PC (or compatible) microcomputer.

Figure 1.—National forests and Indian reservations of the Southwest covered in this study. Not shown are the San Juan, Rio Grande, and San Isabel National Forests of southern Colorado.

Table 1.—Series and habitat type classifications published in the southwest United States, with the geographic areas, national forests (N.F.), Indian reservations (I.R.), and, where appropriate, the forest zone covered.

Authors	Decription
1. Layser and Schubert (1979)	Arizona and New Mexico, all forest zones (series only).
2. Moir and Ludwig (1979)	Arizona and New Mexico, spruce-fir and mixed conifer zones.
3. Hanks et al. (1983)	Northern Arizona, ponderosa pine zone (Kaibab N.F., Coconino N.F., Sitgreaves N.F. Apache N.F.).
4. Alexander et al. (1984b)	Northern Arizona, Douglas-fir zone (Kaibab N.F., Coconino N.F., Sitgreaves N.F., Apache N.F.).
5. Alexander et al. (1984a)	South-central New Mexico, all zones (Lincoln N.F.).
6. DeVelice et al. (1986)	Southern Colorado, northern New Mexico, all zones (Carson N.F., Santa Fe N.F., San Juan N.F., San Isabel N.F., Rio Grande N.F., and adjoining forested lands)*
7. Fitzhugh et al. (1988)	Southeastern New Mexico and west-central Arizona, all zones (Apache N.F.; Sitgreaves N.F.; Gila N.F., and Magdelena District, Cibola N.F.).
8. Alexander et al. (1988)	Central New Mexico, all zones (Cibola N.F., except Magdelena District).
9. Muldavin et al. (1989)	Southern, central and northwestern Arizona, all zones (Coronado N.F., Tonto N.F., Prescott N.F., San Carlos I.R., Ft. Apache I.R., and Hualapai I.R).

**Including NM land grants, Pueblo de Taos I.R., miscellaneous private lands, and Bandelier National Park.*

Using the data base and associated programs, the researcher can print complete, consolidated stand and site characteristics tables of habitat types of the Southwest, organized by climax forest tree series, or create customized tables and data sets to suit individual research needs. Below we describe in detail the content and structure of the data base and how to manipulate it. We expect that the data base and associated tables will give a regional perspective to the nature of the classifications in the Southwest and provide a context for future research.

DATA BASE CONTENT

The data base consists of 2,009 reconnaissance and analytic plots established throughout the region. Table 2 outlines the distribution of the plots by series and habitat type. There are 104 habitat types listed, stratified by 11 climax tree series. Assignment of individual plots to specific habitat types follows that given by investigators in their original publications. The most common habitat type names were used here, following closely the designations recommended by Ludwig and Moir.[3] Synonymous habitat names are given where appropriate. The data base contains information on 1,209 species from across the Southwest (appendix A).

[3]*Ludwig, John A., and William H. Moir. 1984. Comparison table of habitat type nomenclature [Mimeo]. New Mexcio State University, Las Cruces, New Mexico.*

Over the course of the habitat typing project, fiel methods and data collection remained relatively un form. The procedures have been outlined elsewher (Daubenmire and Daubenmire 1968, Franklin et al. 197 Moir and Ludwig 1983, Pfister and Arno 1980), and onl an overview is provided here.

Plots were uniform in size (375 m^2) and were estab lished in representative stands of climax or near clima vegetation that had not been recently disturbed, where ver possible. Plot information included: density of tre species in 2-inch diameter breast height (d.b.h.) class es; estimated or sample percent cover of all shrubs, grass es, and forbs; site characteristics including slope, aspect elevation, and topography; site index evaluation entail ing the measurement of d.b.h., height, and age on u to three trees per plot; and descriptive comments con cerning stand condition, landscape position, and eco tones between adjacent communities.

An example of a plot data sheet is shown in figure 2 Plots were staked and located on USGS topographic quadrangles and documented with up to three photo graphs. Several investigators also included soil profile descriptions, mistletoe ratings, and voucher specimens of plant species found. The bulk of this data was then coded for computer processing and subsequent analysis.

COMPUTERIZED DATA BASE STRUCTURE

We have structured the computerized data base for maximum flexibility in access and manipulation to suit

Table 2.—Habitat types (HT) and phases (PH) of the southwest region listed by climax tree series. Habitat type names follow Ludwig and Moir[1] with synonomous names in parentheses. Abbreviations for habitat type names contain codes for the climax tree species and diagnostic undergrowth species separated by a slash (phase code names are also shown). The HT numbers correspond to the classification variables in the data base: SERIES (SER), HTNO (HT), and PHASE (PH). The total number of plots for each series, habitat type, and phase are also given. The references where descriptions of the types can be found are given by publication number corresponding to the numbers found in table 1.

Name	Abbreviation	Number SER	Number HT	Number PH	No. of plots	References
***Pinus aristata* Series**	**PIAR**	**01**	**00**	**00**	***12***	**1,6**
Pinus aristata/Festuca thurberi HT	PIAR/FETH		01	01	7	6
Pinus aristata/Festuca arizonica HT	PIAR/FEAR		03	01	4	6
Pinus aristata/Ribes montigenum HT (Scree)	PIAR/Scree		02	01	1	6
***Picea engelmannii* Series**	**PIEN**	**02**	**00**	**00**	***115***	**1,6,8,9**
Picea engelmannii/Geum rossii HT	PIEN/GERO		12	01	1	2
Picea engelmannii/Moss HT	PIEN/Moss		03	01	6	2,7,8,9
Picea engelmannii/Vaccinium myrtillus/ Polemonium pulcherrimum HT						
Picea engelmannii PH	PIEN/VAMY/POPU, PIEN		01	01	15	2,6
Abies lasiocarpa PH	PIEN/VAMY/POPU, ABLA		01	02	38	6
Picea engelmannii/Vaccinium myrtillus HT	PIEN/VAMY		02	01	3	7
Picea engelmannii/Senecio cardamine HT						
Abies lasiocarpa PH	PIEN/SECA, ABLA		05	01	8	7
Abies concolor PH	PIEN/SECA, ABCO		05	02	12	7
Picea engelmannii/Acer glabrum HT	PIEN/ACGL		06	01	6	2,5,9
Picea engelmannii/Erigeron eximius HT	PIEN/EREX		10	01	9	7,9
Picea engelmannii/Carex foenea HT	PIEN/CAFO		09	01	2	2,9
Picea engelmannii/Elymus triticoides HT	PIEN/ELTR		07	01	4	2,5
Picea engelmannii/Saxifraga bronchialis HT	PIEN/SABR		08	01	8	6
Picea engelmannii/Heracleum spondylium HT	PIEN/HESP		11	01	3	6
***Abies lasiocarpa* Series**	**ABLA**	**03**	**00**	**00**	***264***	**1,6,9**
Abies lasiocarpa/Mertensia ciliata HT	ABLA/MECI		01	01	14	6
Abies lasiocarpa/Moss HT	ABLA/Moss		02	01	18	6,9
Abies lasiocarpa/Vaccinium myrtillus HT	ABLA/VAMY		03	01	80	2,6,7,8,9
Abies lasiocarpa/Vaccinium myrtillus– Linnaea borealis HT	ABLA/VAMY-LIBO		04	01	21	2,6
Abies lasiocarpa/Vaccinium myrtillus– Rubus parviflorus HT	ABLA/VAMY-RUPA		05	01	14	2,6,7,9
Abies lasiocarpa/Rubus parviflorus HT	ABLA/RUPA		06	01	17	2,6,7,9
Abies lasiocarpa/Senecio sanguisorboides HT	ABLA/SECA		08	01	9	2,5
Abies lasiocarpa/Erigeron eximius HT	ABLA/EREX		07	01	75	2,6,7,8,9
Abies lasiocarpa/Acer glabrum HT	ABLA/ACGL		12	01	3	8
Abies lasiocarpa/Juniperus communis HT	ABLA/JUCO		09	01	7	2
Abies lasiocarpa/Lathyrus arizonicus HT	ABLA/LAAR		10	01	3	2,7
Abies lasiocarpa/Jamesia americana HT	ABLA/JAAM		13	01	1	9
Abies lasiocarpa/Saxifraga bronchialis HT (*Holodicus dumosus*; Scree)	ABLA/SABR		11	01	2	6,7
***Picea pungens* Series**	**PIPU**	**04**	**00**	**00**	***113***	**1,2,5,6,7,8,9**
Picea pungens/Linnaea borealis HT	PIPU/LIBO		01	01	11	2,6
Picea pungens/Senecio cardamine HT	PIPU/SECA		03	01	4	2,7
Picea pungens/Carex foenea HT	PIPU/CAFO		06	01	25	2,5,6,7,8
Picea pungens/Erigeron eximius HT	PIPU/EREX		04	01	24	2,6,7,9
Picea pungens/Fragaria ovalis HT	PIPU/FROV		05	01	6	5
Picea pungens-Pseudotsuga menziesii HT						
Valeriana capitata PH	PIPU-PSME, VACA		13	01	2	2
Picea pungens/Juniperus communis HT	PIPU/JUCO		02	01	1	2,9
Picea pungens/Arctostaphylos uva-ursi HT	PIPU/ARUV		07	01	4	2,6
Picea pungens/Festuca arizonica HT	PIPU/FEAR		08	01	19	6,7
Picea pungens/Swida sericea HT (*Cornus stolonifera*)	PIPU/SWSE		09	01	11	6,8
Picea pungens/Poa pratensis HT	PIPU/POPR		11	01	7	2,6
***Abies concolor* Series**	**ABCO**	**05**	**00**	**00**	***361***	**1,2,5,6, 7,8,9**
Abies concolor/Vaccinium myrtillus HT	ABCO/VAMY		01	01	14	6,9
Abies concolor/Erigeron eximius HT	ABCO/EREX		03	01	32	6,7,9

Name	Abbreviation	Number SER	HT	PH	No. of plots	References
Abies concolor/Acer glabrum HT						
Acer glabrum PH	ABCO/ACGL, ACGL		04	01	43	2,6,7,8,9
Riparian PH	ABCO/ACGL, Riparian		04	02	3	8
Berberis repens PH	ABCO/ACGL, BERE		04	03	5	2,8
Holodiscus dumosus PH	ABCO/ACGL, HODU		04	04	17	2,5,8
Abies concolor/Carex foenea HT	ABCO/CAFO		13	01	4	9
Abies concolor/Sparse HT (*Berberis repens*)	ABCO/Sparse		05	01	66	2,5,6,7,9
Abies concolor/Acer grandidentatum HT						
Acer grandidentatum PH	ABCO/ACGR, ACGR		02	01	14	2,5,7,9
Holodiscus dumosus PH	ABCO/ACGR, HODU		02	02	3	5
Abies concolor/Arctostaphylos uva-ursi HT	ABCO/ARUV		06	01	7	6
Abies concolor/Quercus gambelii HT						
Quercus gambelii PH	ABCO/QUGA, QUGA		07	01	75	2,5,6,7,8,9
Holodiscus dumosus PH	ABCO/QUGA, HODU		07	02	7	5
Festuca arizonica PH	ABCO/QUGA, FEAR		07	03	6	2,5
Muhlenbergia virescens PH	ABCO/QUGA, MUVI		07	04	9	2,5,7,8
Muhlenbergia dubia PH	ABCO/QUGA, MUDU		07	05	?	5
Abies concoler/Lathyrus arizonica HT	ABCO/LAAR		14	01	2	2
Abies concolor/Festuca arizonica HT						
Festuca arizonica PH	ABCO/FEAR, FEAR		09	01	20	6,7,8
Poa fendleriana PH	ABCO/FEAR, POFE		09	02	3	7
Abies concolor/Muhlenbergia virescens HT	ABCO/MUVI		08	01	8	4,7
Abies concolor/Robinia neomexicana HT	ABCO/RONE		10	01	2	2,7
Abies concolor/Elymus triticoides HT	ABCO/ELTR		11	01	4	5
Abies concolor/Jamesia americana HT (*Holodiscus dumosus*; Scree)	ABCO/HODU		12	01	7	6,7
Abies concolor/Juglans major HT	ABCO/JAMA		16	01	6	5,7,9
Abies concolor/Galium triflorum HT	ABCO/GATR		15	01	4	6
***Pinus flexilis* Series**	**PIFL**	**06**	**00**	**00**	***4***	**1,6**
Pinus flexilis/Arctostaphylos uva-ursi HT	PIFL/ARUV		01	01	4	6
***Pseudotsuga menziesii* Series**	**PSME**	**07**	**00**	**00**	***247***	**1,4,5,6,7,8,9**
Pseudotsuga menziesii/Bromus ciliatus HT	PSME/BRCI		01	01	10	7,8
Pseudotsuga menziesii/Sparse (*Berberis repens*)	PSME/Sparse		02	02	20	4,9
Pseudotsuga menziesii/Acer grandidentatum HT	PSME/ACGR		13	01	2	9
Pseudotsuga menziesii/Arctostaphylos uva-ursi HT	PSME/ARUV		07	01	2	7
Pseudotsuga menziesii/Quercus gambelii HT						
Quercus gambelii PH	PSME/QUGA, QUGA		03	01	80	4,5,6,7,8,9
Festuca arizonica PH	PSME/QUGA, FEAR		03	02	14	6,7
Mulenbergia virescens PH	PSME/QUGA, MUVI		03	03	11	4,7
Holodiscus dumosus PH	PSME/QUGA, HODU		03	04	6	5
Pseudotsuga menziesii/Festuca arizonica HT	PSME/FEAR		05	01	26	2,4,6,7,8
Pseudotsuga menziesii/Muhlenbergia virescens HT	PSME/MUVI		04	01	30	2,4,7,9
Pseudotsuga menziesii/Muhlenbergia montana	PSME/MUMO		06	01	13	7,8,9
Pseudotsuga menziesii/Quercus rugosa HT	PSME/QURU		10	01	6	9
Pseudotsuga menziesii/Quercus hypoleucoides HT	PSME/QUHY		08	01	12	2,8,9
Pseudotsuga menziesii/Quercus arizonica HT	PSME/QUAR		12	01	5	9
Pseudotsuga menziesii/Holodiscus dumosus HT (Scree)	PSME/HODU		09	01	5	6,7
Pseudotsuga menziesii/Unclassified	PSME/Unclassified		00	00	5	2
***Pinus ponderosa* Series**	**PIPO**	**08**	**00**	**00**	***806***	**3,5,6,7,8,9**
Pinus ponderosa/Arctostaphylos uva-ursi HT	PIPO/ARUV		01	01	10	6
Pinus ponderosa/Quercus gambelii HT						
Quercus ganbelii PH	PIPO/QUGA, QUGA		02	01	50	5,6,7,8,9
Pinus edulis PH	PIPO/QUGA, PIED		02	02	32	6,8,9
Festuca arizonica PH	PIPO/QUGA, FEAR		02	03	21	6
Muhlenbergia longiligula PH	PIPO/QUGA, MULO		02	05	8	7,9
Schizachyrium scoparium PH	PIPO/QUGA, SCSC		02	06	5	8
Pinus ponderosa/Festuca arizonica HT						
Festuca arizonica PH	PIPO/FEAR, FEAR		03	01	79	3,5,6,7,8,9
Danthonia parryi PH	PIPO/FEAR, DAPA		03	02	7	6
Quercus gambelii PH	PIPO/FEAR, QUGA		03	03	25	3,7,8,9
Boutelous gracilis PH	PIPO/FEAR, BOGR		03	04	45	3,6,7,8

Name	Abbreviation	Number SER	HT	PH	No. of plots	References
Pinus ponderosa/Muhlenbergia virescens–Festuca arizonica HT						
M. virecens–F. arizonica PH	PIPO/MUVI-FEAR, MUVI-FEAR		04	01	52	3,7,8
Quercus gambelii PH	PIPO/MUVI-FEAR, QUGA		04	02	27	3,7
Bouteloua gracilis PH	PIPO/MUVI-FEAR, BOGR		04	03	13	3,7
Pinus ponderosa/Muhlenbergia virescens HT						
Muhlenbergia virescens PH	PIPO/MUVI, MUVI		05	01	36	3,7,8,9
Quercus gambelii PH	PIPO/MUVI, QUGA		05	02	34	3,7,8
Pinus ponderosa/Muhlenbergia montana HT	PIPO/MUMO		06	01	36	3,6,7,8,9
Pinus ponderosa/Bouteloua gracilis HT						
Bouteloua gracilis PH	PIPO/BOGR, BOGR		07	01	36	3,6,8,9
Schizachyrium scoparium PH	PIPO/BOGR, SCSC		07	02	14	6
Pinus edulis PH	PIPO/BOGR, PIED		07	03	20	3,7
Quercus gambelii PH	PIPO/BOGR, QUGA		07	04	19	3
Andropogon halii PH	PIPO/BOGR, ANHA		07	05	16	3
Artemisia tridentata PH	PIPO/BOGR, ARTR		07	06	14	3,9
Pinus ponderosa/Poa longiligula CT[2]	PIPO/POLO		22	01	15	3
Pinus ponderosa/Poa fendleriana CT	PIPO/POFE		23	01	10	3
Pinus ponderosa/Quercus rugosa HT	PIPO/QURU		12	01	11	9
Pinus ponderosa/Quercus hypoleucoides HT	PIPO/QUHY		13	01	22	9
Pinus ponderosa/Quercus arizonica HT						
Quercus arizonica PH	PIPO/QUAR, QUAR		14	01	29	9
Bouteloua gracilis PH	PIPO/QUAR, BOGR		14	02	5	9
Pinus ponderosa/Quercus grisea HT						
Muhlenbergia longiligula PH	PIPO/QUGR, MULO		25	03	9	7
Muhlenbergia montana PH	PIPO/QUGR, MUMO		25	02	7	7
Pinus ponderosa/Quercus undulata HT						
Quercus undulata PH	PIPO/QUUN, QUUN		08	01	16	5,6
Muhlenbergia dubia PH	PIPO/QUUN, MUDU		08	02	8	5
Muhlenbergia longiligula PH	PIPO/QUUN, MULO		08	03	2	5
Pinus ponderosa/Quercus emoryi HT	PIPO/QUEM		15	01	19	9
Pinus ponderosa/Arctostaphylos pungens HT						
Arctostaphylos pungens PH	PIPO/ARPU, ARPU		21	01	12	9
Quercus gambelii PH	PIPO/ARPU, QUGA		21	02	13	3,7
Pinus ponderosa/Artemisia arbuscula HT	PIPO/ARAR		10	01	6	6
Pinus ponderosa/Cowania mexicana CT	PIPO/COME		24	01	1	3
Pinus ponderosa/Ribes inerme HT (Rockland, Scree)	PIPO/RIIN		11	01	5	6,7,8
Pinus ponderosa/Cinder Soils HT	PIPO/Cinder		27	01	4	8
Pinus ponderosa/Acer grandidentatum HT	PIPO/ACGR		16	01	2	9
Pinus ponderosa/Juglans major HT	PIPO/JUMA		17	01	5	9
Pinus ponderosa/Riparian	PIPO/Riparian		26	01	1	8
Pinus ponderosa/Oryzopsis hymenoides HT	PIPO/ORHY		09	01	1	6
Pinus ponderosa/Poa pratensis HT	PIPO/POPR		18	01	3	6
Pinus ponderosa/Unclassified	PIPO/Unclassified		00	00	1	3
***Pinus engelmannii* Series**	**PINEN**	**09**	**00**	**00**	***10***	**9**
Pinus engelmannii/Muhlenbergia longiligula HT	PINEN/MULO		01	01	1	9
Pinus engelmannii/Quercus rugosa HT	PINEN/QURU		02	01	1	9
Pinus engelamnnii/Quercus hypoleucoides HT	PINEN/QUHY		03	01	6	9
Pinus engelmannii/Quercus arizonica HT	PINEN/QUAR		04	01	1	9
Pinus engelmannii/Quercus emoryi HT	PINEN/QUEM		05	01	1	9
***Pinus leiophylla* Series**	**PILE**	**10**	**00**	**00**	**37**	**1,9**
Pinus leiophylla/Piptochaetium fimbriatum HT	PILE/PIFI		05	01	7	9
Pinus leiophylla/Quercus hypoleucoides HT	PILE/QUHY		01	01	9	9
Pinus leiophylla/Quercus arizonica HT	PILE/QUAR		02	01	6	9
Pinus leiophylla/Quercus emoryi HT	PILE/QUEM		03	01	6	9
Pinus leiophylla/Arctostaphylos pungens HT	PILE/ARPU		04	01	8	9
Pinus leiophylla/Quercus toumeyi HT	PILE/QUTO		06	01	1	9
***Populus angustifolia* Series**	**POAN**	**11**	**00**	**00**	**9**	**7**

[1]*Ludwig, John A., and William H. Moir. 1984. Comparison table of habitat type nomenclature* [*Mimeo*], *New Mexcio State University, Las Cruces, New Mexico.*

[2]*Classified as a community type by the authors.*

PLOT____ Crew____________ Date_____

UNDERSTORY					
Shrubs	%C	v	Herbs	%C	v
Herbs	%C	v			

REMARKS:

PLOT________________ photo______

crew________________ date______

state____ phs. prv.____________

NF__________ RD____________

quad.________________ ser.____

T____ R____ S____ 1/4____ zone______

Easting__________ Northing__________

local.______________________

elev.______ slope (%)______ aspect______

pos.________ Par. Mat.____________

soil ser.____________ m. unit________

soil dep. (dm)______ ston.____ rock.____

Lit.____ Soil____ Rock____ BA______

HT/CT______________________

REMARKS:

TREES	NUMBER BY DBH (INCH) CLASS											
	0 - 2		2 - 4	4 - 6	6 - 8	8 - 10	10 - 12	12 - 14	14 - 16	16 - 18	18 - 20	>20
	<4.5'	>4.5'										
P												
P												
P												
P												
P												
P												

TREE	DBH	Ht	Core	REMARKS:

PLOT______ Crew__________ Date____

SOILS (O hors. on reverse)

Horizon________ Depth__________ Texture____________

Struct.____________ Consist.__________ Color________

Frags.____________ Roots______________ Bound.______

Horizon________ Depth__________ Texture____________

Struct.____________ Consist.__________ Color________

Frags.____________ Roots______________ Bound.______

Horizon________ Depth__________ Texture____________

Struct.____________ Consist.__________ Color________

Frags.____________ Roots______________ Bound.______

Horizon________ Depth__________ Texture____________

Struct.____________ Consist.__________ Color________

Frags.____________ Roots______________ Bound.______

Figure 2.—Examples of field data cards where separate cards are used for location/site characteristics, plant inventory, tree inventory, and soils.

various research needs. There are two major partitions to the data base: (1) source data files containing the actual vegetation and site characteristics data organized by climax tree series; and (2) the program and parameter files used to manipulate the source data. The entire data set is in ASCII format on 5 1/4-inch floppy disks, which are compatible with IBM MS-DOS, and is available upon request from the Rocky Mountain Forest and Range Experiment Station.[4] The data files can be read, edited, and subsetted by a microcomputer (given an appropriate FORTRAN compiler), and it may be possible, depending on the microcomputer hardware on hand, to analyze small data sets. The analysis of large data sets will probably require the larger capacity of a mini- or mainframe computer.

Source Data Files

The format of the original data files was developed by John Ludwig[5] and provides for maximum flexibility in data entry and manipulation; at the same time it is compact, minimizing storage space requirements. Coded information includes species abundances and site and location information. The consolidated data files were constructed by merging the data sets from each study listed in table 1 and then re-sorting the plots by climax tree series, habitat type, and phase. For example, plots of the *Abies lasiocarpa/Vaccinium myrtillus* habitat type found in northern New Mexico and southern Colorado (DeVelice et al. 1986) were merged with all other plots from that habitat type found in southern New Mexico and Arizona (Alexander et al. 1988, Fitzhugh et al. 1988, Muldavin et al 1989). Habitat types were then grouped into data files by series. Thus, all data are initially accessed by series and then manipulated to meet specific needs. The data files can be used with the programs provided to produce customized site characteristics tables similar to those in appendix C, or they can be subsetted for use in external programs.

Vegetation Files

The vegetation data files contain the species abundance values by plot and are used to construct stand tables similar to those in appendix B, or they can be subsetted and reformatted for use in other external programs. The vegetation data files are listed in table 3.

Figure 3 provides an example of how the vegetation abundance values are coded in the files. Each plot is represented by one to many lines (cards, card images), depending on the number of species in the plot. The first line contains a unique plot identifier in columns 1–5. Column 1 contains the code of the principal investigator who established the plot (table 4). Column 2 is a general location identifier (table 5). Columns 3–5 contain a plot number which was assigned by the principal investigator. Columns 7–8 contain the number of species observations in the plot.

Following the number of species observations is a series of couplets consisting of species codes and associated abundance values. There are as many couplets as the number of species. The couplets are nine columns wide; the first six columns contain the alphanumeric species code, while the last three columns contain the numeric abundance value for that species. Tree species abundances are in stems per plot (375 m^2), presented in three broad size classes. For example, young regeneration of *Pinus leiophylla* (<2 inches d.b.h.) is recorded as PILE1, advanced regeneration (2–10 inches d.b.h.) as PILE2, and mature trees (>10 inches d.b.h.) as PILE3. The shrub, grass, and herb species values are in percent cover. A [+0] abundance value indicates that the species was present in the stand, but not in the plot. There are a maximum of eight couplets to a line, and the couplets continue on succeeding lines until all the species indicated by the number species in columns 7–8 are represented. A complete list of species names and codes is presented in appendix A.

The last three "species" couplets of each plot are special classification variables: SERIES, HTNO, and PHASE. Values associated with these variables correspond to the identification numbers found in table 2 for the series, habitat type, and phase, respectively.

Table 3.—Vegetation source data files available on floppy disks. The first four letters of the filename give the series code (as in table 2) followed by VEG to indicate that they are vegetation files, plus the file extension .DAT to indicate that they contain source data.

Disk no.	File name	Data description	Size
1	PIPUVEG.DAT	*Picea pungens* Series	60 K
1	PIARVEG.DAT	*Pinus aristata* Series	5 K
1	PIENVEG.DAT	*Picea engelmannii* Series	41 K
1	PIFLVEG.DAT	*Pinus flexilis* Series	1 K
1	PILEVEG.DAT	*Pinus leiophylla* Series	16 K
1	PINENVEG.DAT	*Pinus engelmannii* Series	3 K
1	POANVEG.DAT	*Popoulus angustifolia*	1 K
2	PIPOVEG.DAT	*Pinus ponderosa* Series	294 K
3	ABCOVEG.DAT	*Abies concolor* Series	152 K
3	ABLAVEG.DAT	*Abies lasiocarpa* Series	98 K
3	PSMEVEG.DAT	*Pseudotsuga menziesii* Series	93 K

Table 4.—Principal investigator codes used in the data base plot identification codes.

Code	Principal investigator
A	Alexander, Billy G.
E	Muldavin, Esteban H.
F	Fitzhugh, E. Lee
D	DeVelice, Robert L.
L	Ludwig, John A.
M	Moir, William H.
W	White, Alan S.

[4] *Rocky Mountain Forest and Range Experiment Station, 240 W. Prospect Road, Fort Collins, Colo. 80526.*

[5] *Work performed while a professor at New Mexico State University, Las Cruces, New Mexico. Current address: Rangelands Research Center, Deniliquin, New South Wales 2710 Australia.*

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                                    COLUMNS
0        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

EK 34 37 PILE1   4 PILE2   4 PILE3   7 QUHY0  27 QUHY1  59 QUHY2  24 QUAR0  28 QUAR1   2
         QUAR2  12 JUDE1   3 JUDE2   1 ARAR2   3 ARAR3   1  QUHY  25  QUAR  10  YUBA   1
          GAWR.01   ARAR .1   RHAR.05 AGPAR.05   MULO .5   BRCI.01   EROR.01   SENE.01
          HEDE.01   CHFE .1   GAMI.05ASTRAG.01   HEHY .1GNAPHA.01 DALEA +0 UNID1.01
         UNID2.01 UNID3.01SERIES 10   HTNO 01 PHASE 01
EW109 38 PILE1  16 PILE2  19 PILE3   4 PIPO1  21 PIPO2  11 PIPO3   1PIPOT1  21PIPOT2  11
        PIPOT3   1 QUHY0  40 QUHY1   8 QUHY2  14 QUEM0   2 QUEM1   2 QUEM2   2 QUGR0   3
          QUHY  15  QUEM   6  JUDE .1   ARPR +0   OPPL.01   NOMI.01   CEFE .1   ARPU .1
          QUGR.01   CABI .1   CAGE.01   HEHY.01   ARCA .2   SENE.01   SOSP.05   LINE.01
          IPAG +0   AGHE +0   SILI.01SERIES 10   HTNO 01 PHASE 01
DK 17 17 PILE1   6 PILE2   5 PILE3   7 QUHY1100 QUHY2  46 ARAR2   3 QUAR2   1 JUDE1   1
         PIDI1   3  QUHY  65  QURU .1   ARAR   6  QUAR   1  MULO   3SERIES 10   HTNO 01
         PHASE 01
           .        .        .        .        .        .        .        .
           .        .        .        .        .        .        .        .
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Figure 3.—An example of the structure of a vegetation source data file. See text for details.

Table 5.—Location codes used in the data base plot identification codes.

Code	Location
C	Cibola National Forest, central New Mexico.
G	Gila National Forest, southwestern New Mexico, Apache National Forest, eastern Arizona.
H	Hualapai Indian Reservation, northwest Arizona.
K	Coronado National Forest, southeastern Arizona.
L	Lincoln National Forest, south-central New Mexico.
M	Mogollon Plateau, including the Coconino, Apache, Sitgreaves, and Kaibab National Forests of northern Arizona.
N	Northern New Mexico and southern Colorado, including the Santa Fe, Carson, San Isabel, San Juan, and Rio Grande National Forests.
P	Prescott National Forest, west-central Arizona.
S	San Carlos Indian Reservation, central Arizona.
T	Tonto National Forest, central Arizona.
W	Fort Apache Indian Reservation (White River), east-central Arizona.

Site Characteristics Files

The structure of the site characteristics files is fundamentally different from the vegetation files. Data are coded in a fixed column format where each column or set of columns refers to a specific environmental variable. Figure 4 gives an example of the plot coding structure. There are two lines per plot. The first 5 columns of line 1 give the same unique plot identifier as outlined above under the vegetation files. The remaining columns have specific meanings, which are given in table 6. For example, elevation (in feet) can be found on line 2 in columns 42–46. The site characteristics files that are available are listed in table 7.

Data Manipulation: Programs and Parameter Files

To manipulate the data base, a suite of programs and associated data definition parameter files is provided. Using these programs and parameter files, complete stand and site characteristics tables like those shown in appendixes B and C can be directly produced. Alternatively, programs and procedures are provided for subsetting and restructuring the data base either to produce customized tables or to create new data sets for use in external programs.

The programs are based on algorithms developed by John Ludwig[5] that were written in ASCII FORTRAN VII for an IBM 370 mainframe. We have rewritten the pro-

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                                    COLUMNS
0         1         2         3         4         5         6         7         8
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EK 19185 720AZ SANTA CATALINA CORONADO  SANTA CATALINABELLOTA RANCH 2
     2 12 53050 358350BEAR CAN GREEN MTTR 6900 17 1225GRANITE100401  60 230 0 3
MK988183 9 6NM FELONCILLO MTNSCORONADO  DOUGLAS       APACHE        231S21W31SE
     2                 WALNUT  CANYON     5600  2  190RHY--ALL100201  95 5 T 0
DK 301821014AZ CHIRICAHUA MTNSCORONADO  DOUGLAS       CHIRICAHUA PK 218S29E24NE
     2 12              POLE BRIDGE CAN    6400 19 4 22RHYOLIT100101  95 0 2 T 3

  .     .     .     .     .     .     .     .     .     .     .     .     .
  .     .     .     .     .     .     .     .     .     .     .     .     .

--------------------------------------------------------------------------------
```

Figure 4.—An example of a site characteristics source data file structure. See text for details.

Table 6.—Column location of site characteristics variables in the source site characteristics data files.

Card	Columns	Variable
1	1	Principal investigator code
1	2	General location code
1	3–5	Plot number as assigned by Principal Investigator
1	6	Card number 1
1	7–8	Sampling date – year
1	9–10	Sampling date – month
1	11–12	Sampling date – day
1	13–14	State abbreviation
1	16–30	Physiographic region
1	31–40	National forest
1	41–54	Ranger district
1	55–68	USGS topographic quadrangle
1	69	Quadrangle series
1	70–72	Township
1	73–75	Range
1	76–77	Section
1	78–79	Quarter section
2	1	Null
2	2	Null
2	3–5	Null
2	6	Card number
2	8–9	UTM zone
2	11–15	UTM easting coordinates (to the nearest 10 meters)
2	17–22	UTM northing coordinates (to the nearest 10 meters)
2	23–41	Location description – locality
2	42–46	Elevation (feet)
2	47–49	Slope (percent)
2	50–51	Topographic position
2	52–54	Aspect (degrees azimuth)
2	55–61	Parent material
2	62–63	Series identification number (as in table 2)
2	64–65	Habitat type identification number (as in table 2)
2	66–67	Phase identification number (as in table 2)
2	70–71	Percent ground cover – litter
2	72–73	Percent ground cover – soil
2	74–75	Percent ground cover – rock
2	76–77	Percent ground cover – moss
2	78–79	Percent ground cover – basal area

Table 7.—Site characteristics source data files available on floppy disk.

File name	Data description	Size
PSMESITE.DAT	*Pseudotsuga menziesii* Series	38 K
ABCOSITE.DAT	*Abies concolor* Series	57 K
PIPUSITE.DAT	*Picea pungens* Series	16 K
PIENSITE.DAT	*Picea engelmannii* Series	17 K
ABLASITE.DAT	*Abies lasiocarpa* Series	40 K
PIARSITE.DAT	*Pinus aristata* Series	2 K
PIFLSITE.DAT	*Pinus flexilis* Series	1 K
PILESITE.DAT	*Pinus leiophylla* Series	6 K
PINENSIT.DAT	*Pinus engelmannii* Series	2 K
PIPOSITE.DAT	*Pinus ponderosa* Series	109 K
POANSITE.DAT	*Populus angustifolia* Series	1 K

grams in Microsoft FORTRAN to be compiled and run on an IBM PC compatible machine. We have provided both the source code and the already compiled, executable form of the programs on the floppy disks. The executable forms (.EXE) are available for immediate use. The programs request data file names and other information interactively. If your machine cannot handle interactive file information, the source code can be altered accordingly and recompiled (see examples given in the program documentations). A "readme" file should be present on the floppy disks provided which will contain any program updates or changes.

The programs available, their general purpose, and input requirements are listed in table 8. Basic input requires the above defined data files (.DAT files), and may require data definition parameter files (.PAR files). These parameter files are specially structured to direct data entry in the programs and consist generally of data definition lines, a list of species codes of species desired for a particular analysis, and a corresponding list of plots. An example of a parameter file is given in figure 5. In columns 3–6 of the first line is the value "9999" to indicate the beginning of a series definition sequence. Columns 7–11 indicate the number of species codes in the species code list that follows. Columns 13–79 are reserved for a user-supplied title for the series and analysis. The second line contains the series number in columns 1–2, which corresponds to the series number found in table 2.

Following the series number line is a list of species codes, one to a line, with the code in columns 2–7. Codes for desired species must correspond to the species on the list in appendix A. There are as many species code lines as indicated by the number of species on line 1. The species are usually ordered as desired for output in a stand table (see "Creating a Stand Table" below). The order is irrelevant when the users intention is to subset a data set with the selection programs provided (see "Creating Data Subsets").

After the species codes lines is a habitat type definition line where columns 2–6 indicate the number of plots from that habitat type to be input, and columns 13–79 are reserved for a user supplied title. Following the habitat type definition line is the habitat type number line, with the series number in columns 1–2, the habitat type number in columns 3–4, and the phase number in

Table 8.—Programs available on floppy disk for manipulating data files.

File name	Program purpose and input
SITETAB.FOR	Outputs site characteristics tables with a source site data file (.DAT file) and a data definition parameter file (.PAR file) as input.
VEGTAB.FOR	Outputs vegetation stand tables with a source vegetation data file (.DAT file), the SWSPP.LIS file, and a data definition parameter file as input.
PAC.FOR	Condenses file definition parameter files (.PAR files).
UNPAC.FOR	Restores file definition parameter files (.PAR files) to an un-condensed format.
VEGSEL.FOR	Creates new vegetation source data sets based on the species and plots input with a file definition parameter file (.PAR file) and a vegetation data file (.DAT file).
SITESEL.FOR	Creates new site characteristics data files based on the plots entered in a data definition parameter file (.PAR file) and a source data file (.DAT file).
VEGMAT1.FOR	Restructures a vegetation data file (.DAT file) into matrix format with species in rows and plots in columns as defined by a data definition parameter file (.PAR file).
VEGMAT2.FOR	Restructures a vegetation data file (.DAT) into matrix format with plots in rows and species in columns as defined by the data definition parameter file (.PAR).
SPPSEL.FOR	Creates new source data files which contain a specified species.
VEGIN.SAS	SAS program to create vegetation (stand) system files from data files (.DAT) for statistical analysis.
SITEIN.SAS	SAS program to create site characteristics system files from site data files for statistical analysis.
CORTAB.FOR	Converts data files to Cornell Ecology Programs Series format.
SPPOBS.FOR	Determines the number of observations for selected species in a data set.

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                                COLUMNS
0        1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::
  9999  298 SOUTHWESTERN HABITAT TYPES: PINUS LEIOPHYLLA SERIES
10 0 0
  TREES
  PIED1
  PIST2
  QUAR2
  QUGR3
 SHRUBS
  ARBAR
  GRASS
 ARISTI
 CYPERU
   ORMI
  FORBS
    .
    .
    .
   PEBA
   SALE
   SILI
      9      PINUS LEIOPHYLLA/QUERCUS HYPOLEUCOIDES HT
10 1 1
 EK 20
 EK 34
 EW109
 DK 17
 DK 30
 DK 35
 DK 45
 DK 32
 DK  6
     10      PINUS LEIOPHYLLA/QUERCUS ARIZONICA HT
10 2 1
 ET 69
 MK988
 DK  3
 DK  4
 DK 39
 DK 44
 DK  5
 DK 68
 EW105
 DK 24
      6      PINUS LEIOPHYLLA/QUERCUS EMORYI HT
10 3 1
    .
    .
    .
------------------------------------------------------------------------
```

Figure 5.—An example of a file definition parameter file. See text for details.

columns 5–6. These numbers correspond to those found in table 2 for individual habitat types. Next, the plot identification codes are listed, one to a line, in columns 2–6, for as many lines as there are plots indicated on the habitat type definition line. The format of the plot code must match that in the data files. The plots are ordered as desired for listing in the stand and site characteristics tables. The sequence of habitat type definition line, habitat type number line, and plot list lines is repeated for as many habitat types as wanted.

The data definition parameter files designed for the output of tables like those found in appendixes B and C are provided on floppy disk (see table 9). To conserve space on the disk, files were put in a condensed format using the program PAC.FOR where there are eight species codes to a line and 10 plots per line. Use program UNPAC.FOR to unpack these files into the format shown in figure 5. PAC.FOR and UNPAC.FOR are simple, small programs that should easily operate on a microcomputer.

Creating Data Subsets

The programs VEGSEL.FOR and SITESEL.FOR are used to subset new source vegetation and site characteristics data files from the data base to meet specific research needs. The input required is a data definition parameter file (.PAR file) and a corresponding initial source data file (.DAT file). The parameter file should be designed to contain only those species and plots desired in the new data sets. Output is in the same format as the original input data files. Currently, the programs are dimensioned for up to 1,000 plots and 1,300 species, as defined in the parameter file.

Table 9.—File definition parameter files available to create the stand tables in appendixes B and C.

File name	Data description	Size
ABLALIST.PAR	*Abies lasiocarpa* Series	6 K
ABCOLIST.PAR	*Abies concolor* Series	8 K
PIENLIST.PAR	*Picea engelmannii* Series	5 K
PIPULIST.PAR	*Picea pungens* Series	5 K
PSMELIST.PAR	*Pseudotsuga menziesii* Series	7 K
PIPOLIST.PAR	*Pinus ponderosa* Series	14 K
PIARLIST.PAR	*Pinus aristata* Series	1 K
PIFLLIST.PAR	*Pinus flexilis* Series	1 K
PINENLIS.PAR	*Pinus engelmannii* Series	2 K
PILELIST.PAR	*Pinus leiophylla* Series	3 K
POANLIST.PAR	*Populus angustifolia* Series	1 K
SWSPP.LIS	Species names, codes, and synonomy for all species in the database.	20 K

Table 10.—Scalar conversions of density (stems/375 m^2) for tree species and percent cover for shrub, grass, and forb species. The scalar values are use in the output of stand tables by the program VEGTAB.FOR.

Density conversion		Percent cover conversion	
Scalar	Density (stems)	Scalar	Percent cover
+	= 1	P	= +0 (present)
1	= 2	+	= < 1
2	= 3–4	1	= 1–4
3	= 5–9	2	= 5–24.9
4	= 10–20	3	= 25–49.9
5	= 21–40	4	= 50–74.9
6	= 41–60	5	= 74–100
7	= 61–80		
8	= 81–99		
9	= > 100		

The program VEGMAT1.FOR takes the same input as above—a parameter file and vegetation data file—but creates an output file in matrix format with species in rows going down and plots in columns going across. VEGMAT2.FOR performs the same function, except that plots are in rows and species in columns.

The program VEGIN.SAS is a special program written in Statistical Analysis System (SAS) programming language (SAS Inc. 1986). The program makes it possible to input vegetation data files (.DAT files) and create SAS system files for statistical analysis. Cases in the system files are equivalent to plots and are identified by the same plot identification code as in the data file. Variables are species, identified by the species code. Correspondingly, SITEIN.SAS is an example of how to input site characteristics data into SAS to create a SAS site characteristics system file. These SAS programs require a large amount of disk space and memory for use with the larger data sets and are, thus, suited primarily for mini- or mainframe computers.

Creating a Stand Table

The program VEGTAB.FOR creates vegetation stand tables similar to the one shown in appendix B. Input files required are: (1) a data definition parameter file (.PAR) with species codes and plot numbers in desired output order; (2) the SWSPP.LIS file containing the species list for the data base; and (3) the appropriate vegetation data file (.DAT) containing the plots listed in the above parameter file. The tables are 80 columns wide, with the first 30 columns reserved for the species name, followed by up to 50 columns containing the abundance values for each of 50 plots. Species abundance values are converted into one column scalars as shown in table 10. The tables can be customized by simply adding, deleting, or rearranging species code and plot lists in parameter files; but, remember to reset the number of species or number of plots on the data definition lines.

Creating a Site Characteristics Table

Procedures for producing site tables are similar to creating a stand table. Using the program SITETAB.FOR, input the same data definition parameter file used for the vegetation stand table along with the corresponding site characteristics file (the SWSPP.LIS file is *not* required).

The program presently reads and outputs only selected site and location characteristics as shown in the tables in appendix C. If other variables are desired, the appropriate dimension, read, and write statements will need to be altered. See "Site Characteristics Files" and table 6 above for the variables available and their location in the data files. The program automatically converts elevation in feet to meters and performs a cosine transformation of the azimuth into a crude solar index where a value of 2.0 = northeast and 0.0 = southwest. The program is currently dimensioned for 1,000 plots.

Creating Summary Stand Tables

Summary tables, similar in form to those found in the publications listed in table 1, can be produced using the program SUMTAB.FOR. Input is identical to that required to produce a normal stand table using VEGTAB.FOR described above. The program outputs a table of mean abundance values and percent constancy per habitat type for each species in the parameter file. A word of warning: SUMTAB.FOR requires considerable memory space to run large data sets (see program documentaion).

Individual Species Information

The program SPPSEL.FOR is an interactive program that allows the user to input a particular species code(s) and vegetation data file. The program will then search the data for those plots containing the species and output a new data set of those plots along with a listing.

The program SPPOBS.FOR takes as input a vegetation data file (.DAT) and the species list (SWSPP.LIS) and outputs the number of observations per species in the particular data file.

NONCOMPUTERIZED DATA

Included in the data base is a wide variety of noncomputerized information which is on file at the library of the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. All original plot records, with associated photographs, are available. Plot records contain detailed stand structures, site index tree measurements, soil profile descriptions, and qualitative descriptions of the stands. Precise plot locations as shown on USGS quadrangles are also available. The original stand and site tables from the publications listed in table 1, along with hard copies of the data base provided here, are also archived in the Rocky Mountain Station library.

THE SERIES STAND AND SITE TABLES

The primary analytic tools used to develop the classifications were table manipulation, cluster analysis, and ordination. The results of analysis are stand and site characteristics tables, where plots with similar species compositions and site characteristics are grouped together to define the habitat types. The habitat type classifications are then summarized by deriving, from the stand tables, the mean species abundance values and constancy (percent occurrence) per habitat type and then presenting them in the form of a summary table. Normally, only summary tables are published, not the stand tables. The process of summarization leads to information loss on the distribution of species in and among habitat types, and can gloss over anomalies and subpatterns in the data. Thus, the stand tables, rather than the summary tables, provide the best and most accurate picture of the classification structure. For this reason, we compiled new regional stand tables and site characteristics tables which contain all the plots from the data base stratified by climax forest tree series. To conserve space, only limited examples of these stand and site tables using the *Picea engelmannii* series are provided in appendixes B and C. The data base files currently available (tables 3, 7, and 9) are structured to create these consolidated stand tables directly using the programs provided (table 8). To output a complete set of regional consolidated stand and site tables, use these data files and the programs and follow the procedures outlined above in "Creating a Stand Table" and "Creating a Site Characteristics Table."

Plots in the stand tables are classified and ordered as they were by the original investigators, with habitat type numbers corresponding to those found in table 2. In a few cases, plots were either not classified or were misclassified by the respective investigators. Based on our knowledge of the regional distribution of habitat types, we have attempted to place such plots into the most appropriate existing habitat type. The major series stand tables (*Pinus ponderosa, Pseudotsuga menziesii, Abies concolor, Picea pungens, Picea engelmannii*, and *Abies lasiocarpa*) contain all species that were observed in more than two stands[6] within a respective series. Tables of the minor series (*Pinus engelmannii, Pinus leiophylla, Pinus aristata*, and *Pinus flexilis*) have complete species lists. Elements identified only to the generic level were excluded from all tables as well. All genera and species present within each series are indicated on the species list in appendix A. For information on uncommon species not listed on the tables, refer to the procedures above on "Individual Species Information."

In the site characteristics tables (appendix C), plots are ordered as in the stand tables. We have included only the most important site and location characteristics on these tables. For a complete list of environmental information available see the above "Site Characteristics Files" section.

These tables represent the current status of habitat typing in the Southwest. We hope that future work, using these tables and the associated data base, will help clarify and more precisely delineate differences among forest communities of the region.

[6]*The reader is reminded of habitat type terminology (e.g., Moir and Ludwig 1983) whereby a plot is a sampled portion of the larger homogeneous stand.*

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APPENDIX A

Vascular Plant Species Found in Forest Habitat Types of the Southwest

Species names variously follow Kearny and Peebles (1951), Martin and Hutchins (1980–81), and Weber and Johnston (1979). Shown are: species names, with any relevant synonymy in parentheses; the number of total observations in the data base; and a presence/absence code for the series in which a species is found. A [+] indicates that the species is listed in the series stand tables. A [•] indicates no observation for that series.

Tree species are represented in the data by up to three size classes as follows:

Young regeneration (Yng regen): less than 2 inches d.b.h.

Advanced regeration (Adv regen): 2 to 10 inches d.b.h.

Mature: greater than 10 inches d.b.h.

Series numbers (No.) correspond to the following climax forest series:

01 = *Pinus aristata*
02 = *Picea engelmannii*
03 = *Abies lasiocarpa*
04 = *Picea pungens*
05 = *Abies concolor*
06 = *Pinus flexilis*
07 = *Pseudotsuga menziesii*
08 = *Pinus ponderosa*
09 = *Pinus engelmannii*
10 = *Pinus leiophylla*
11 = *Populus angustifolia*

SPECIES NAME		SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
----------------- TREES -----------------		TREE												
Abies concolor														
	Yng regen	ABCO1	573	.	+	+	+	+	+	+	+	.	.	+
	Adv regen	ABCO2	512	.	+	+	+	+	+	+	+	.	.	+
	Mature	ABCO3	374	+	+	+	+	+	.	+	+	.	.	+
Abies lasiocarpa														
	Yng regen	ABLA1	375	+	+	+	+	+	+	+	.	.	.	.
	Adv regen	ABLA2	339	+	+	+	+	+	.	+	.	.	.	.
	Mature	ABLA3	272	.	+	+	+	+	.	+	.	.	.	.
Acer glabrum														
	Yng regen	ACGL1	35	.	+	+	+	+	.	.	.	.	.	.
	Adv regen	ACGL2	21	.	+	+	.	+	.	.	.	.	.	.
	Mature	ACGL3	2	.	.	.	.	+	.	.	.	.	.	.
Acer grandidentatum														
	Yng regen	ACGR1	13	.	.	.	.	+	.	+	+	.	.	.
	Adv regen	ACGR2	10	.	.	.	.	+	.	+	+	.	.	.
	Mature	ACGR3	3	.	.	.	.	+	.	.	.	.	.	.
Acer negundo														
	Yng regen	ACNE1	8	.	.	.	.	+	.	.	+	.	.	.
	Adv regen	ACNE2	8	.	.	.	.	+	.	.	+	.	.	.
	Mature	ACNE3	5	.	.	.	.	+	.	.	+	.	.	.
Alnus spp.														
	Yng regen	ALNUS1	5	.	+	.	+	.	.	.	.	.	.	.
Alnus oblongifolia														
	Yng regen	ALOB1	2	.	.	.	.	+	.	.	.	.	.	+
	Adv regen	ALOB2	3	.	.	.	.	.	.	.	.	.	.	+
	Mature	ALOB3	7	.	.	.	.	.	.	.	+	.	.	+
Alnus tenuifolia														
	Yng regen	ALTE1	5	.	+	+	+	.	.	.	.	.	.	.
	Adv regen	ALTE2	5	.	+	+	+	.	.	.	.	.	.	.
Arbutus arizonica														
	Yng regen	ARAR1	4	.	.	.	.	.	.	+	+	+	.	.
	Adv regen	ARAR2	14	.	.	.	.	.	.	+	+	+	+	.
	Mature	ARAR3	4	.	.	.	.	.	.	.	+	.	+	.
Arbutus xalapensis														
	Yng regen	ARXA1	1	.	.	.	.	.	.	.	+	.	.	.
	Adv regen	ARXA2	2	.	.	.	.	.	.	.	+	.	.	.
Forestiera neomexicana														
	Yng regen	FONE1	1	.	.	.	.	.	.	.	+	.	.	.
	Adv regen	FONE2	1	.	.	.	.	.	.	.	+	.	.	.
Fraxinus anomala														
	Yng regen	FRAN1	1	.	.	.	.	+	.	.	.	.	.	.
	Adv regen	FRAX2	1	.	.	.	.	.	.	.	+	.	.	.
Fraxinus pennsylvanica														
	Yng regen	FRPE1	16	.	.	.	.	+	.	+	+	.	.	.
	Adv regen	FRPE2	7	.	.	.	.	+	.	+	+	.	.	.
Juglans major														
	Yng regen	JUMA1	18	.	.	.	.	+	.	+	+	.	.	.
	Adv regen	JUMA2	10	.	.	.	.	+	.	.	+	.	+	.
	Mature	JUMA3	5	.	.	.	.	+	.	.	+	.	.	.

SPECIES NAME		SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
------------------ TREES ------------------		TREE												
Juniperus deppeana														
	Yng regen	JUDE1	359	.	.	.	.	+	.	+	+	+	+	+
	Adv regen	JUDE2	226	.	.	.	.	+	.	+	+	+	+	+
	Mature	JUDE3	117	.	.	.	.	+	.	+	+	+	+	.
Juniperus monosperma (Incl: *J. erythrocarpa*)														
	Yng regen	JUMO1	71	.	.	.	.	+	.	+	+	.	+	.
	Adv regen	JUMO2	39	.	.	.	.	.	.	.	+	.	+	+
	Mature	JUMO3	7	.	.	.	.	.	.	.	+	.	.	.
Juniperus osteosperma (*J. utahensis*)														
	Yng regen	JUOS1	31	.	.	.	.	+	.	.	+	.	.	.
	Adv regen	JUOS2	24	.	.	.	+	+	.	.	+	.	.	.
	Mature	JUOS3	5	.	.	.	.	.	.	.	+	.	.	.
Juniperus scopulorum														
	Yng regen	JUSC1	135	.	.	.	+	+	.	+	+	.	.	+
	Adv regen	JUSC2	102	.	.	.	+	+	.	+	+	.	.	+
	Mature	JUSC3	23	.	.	.	.	+	.	+	+	.	.	.
Picea engelmannii														
	Yng regen	PIEN1	412	+	+	+	+	+	+	+	+	.	.	.
	Adv regen	PIEN2	413	+	+	+	+	+	+	+	.	.	.	.
	Mature	PIEN3	377	+	+	+	+	+	+	+	.	.	.	.
Picea pungens														
	Yng regen	PIPU1	177	.	+	+	+	+	.	+	+	.	.	.
	Adv regen	PIPU2	175	.	+	+	+	+	.	+	+	.	.	.
	Mature	PIPU3	136	.	+	+	+	+	.	+	+	.	.	.
Pinus aristata														
	Yng regen	PIAR1	19	+	.	+	.	+	.	+	+	.	.	.
	Adv regen	PIAR2	18	+	+	+	.	+	.	+	+	.	.	.
	Mature	PIAR3	16	+	+	+	.	+	.	.	.	.	.	.
Pinus contorta														
	Yng regen	PICO1	3	.	.	+	.	+	.	.	.	.	.	.
	Adv regen	PICO2	5	.	.	+	.	+	.	.	.	.	.	.
	Mature	PICO3	3	.	.	+	.	+	.	.	.	.	.	.
Pinus discolor														
	Yng regen	PIDI1	59	.	.	.	.	+	.	+	+	+	+	.
	Adv regen	PIDI2	29	.	.	.	.	.	.	+	+	+	+	.
Pinus edulis														
	Yng regen	PIED1	362	.	.	.	.	+	.	+	+	+	.	+
	Adv regen	PIED2	165	+	.	+	.	+	.	+	+	+	.	.
	Mature	PIED3	15	.	.	.	.	.	.	+	+	.	.	.
Pinus flexilis (Incl: X *P. strobiformis*)														
	Yng regen	PIFL1	102	+	+	+	+	+	+	+	+	.	.	.
	Adv regen	PIFL2	77	.	.	+	+	+	+	+	+	.	.	.
	Mature	PIFL3	49	+	+	+	+	+	+	+	+	.	.	.
Pinus leiophylla														
	Yng regen	PILE1	47	.	.	.	.	.	.	.	+	+	+	.
	Adv regen	PILE2	49	.	.	.	.	.	.	.	+	+	+	.
	Mature	PILE3	48	.	.	.	.	.	.	.	+	+	+	.

SPECIES NAME		SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
----------------- **TREES** -----------------		**TREE**												
Pinus monophylla														
	Yng regen	PIMO1	2	.	.	.	.	.	.	.	+	.	.	.
Pinus engelmannii (*P. latifolia*)														
	Yng regen	PINEN1	13	.	.	.	.	.	.	.	+	+	+	.
	Adv regen	PINEN2	11	.	.	.	.	.	.	+	.	+	+	.
	Mature	PINEN3	17	.	.	.	.	.	.	+	+	+	+	.
Pinus ponderosa (Incl: *P. arizonica*)														
	Yng regen	PIPO1	1054	.	+	.	+	+	.	+	+	.	+	+
	Adv regen	PIPO2	1067	.	+	+	+	+	+	+	+	+	+	+
	Mature	PIPO3	1242	.	+	+	+	+	.	+	+	.	+	+
Pinus strobiformis														
	Yng regen	PIST1	423	.	+	+	+	+	.	+	+	+	.	+
	Adv regen	PIST2	342	.	+	+	+	+	.	+	+	.	.	+
	Mature	PIST3	226	.	+	+	+	+	.	+	+	.	.	+
Platanus wrightii														
	Yng regen	PLWR1	1	.	.	.	.	.	.	.	.	.	+	.
	Adv regen	PLWR2	1	.	.	.	.	.	.	.	.	.	+	.
	Mature	PLWR3	3	.	.	.	.	.	.	.	+	.	+	.
Populus angustifolia														
	Yng regen	POAN1	12	.	+	.	+	+	.	.	+	.	.	+
	Adv regen	POAN2	13	.	+	.	+	+	.	+	+	.	.	+
	Mature	POAN3	21	.	+	+	+	+	.	.	+	.	.	+
Populus tremuloides														
	Yng regen	POTR1	163	+	+	+	+	+	+	+	+	.	.	.
	Adv regen	POTR2	284	.	+	+	+	+	+	+	+	.	.	+
	Mature	POTR3	218	.	+	+	+	+	.	+	+	.	.	.
Prunus serotina (ssp. *virens*; *P. virens*)														
	Yng regen	PRSE1	6	.	.	.	.	.	.	+	+	.	+	.
	Adv regen	PRSE2	3	.	.	.	.	.	.	+	+	.	+	.
	Mature	PRSE3	1	.	.	.	.	.	.	+	.	.	.	.
Pseudotsuga menziesii														
	Yng regen	PSME1	926	+	+	+	+	+	+	+	+	+	+	+
	Adv regen	PSME2	876	+	+	+	+	+	+	+	+	+	+	+
	Mature	PSME3	795	+	+	+	+	+	+	+	+	+	+	+
Quercus arizonica (Incl: X *Q. grisea*)														
	Yng regen	QUAR1	73	.	.	.	.	.	.	+	+	+	+	.
	Adv regen	QUAR2	113	.	.	.	.	.	.	+	+	+	+	.
	Mature	QUAR3	56	.	.	.	.	.	.	+	+	+	+	.
Quercus chrysolepis (*Q. wilcoxii*; *Q. palmeri*)														
	Yng regen	QUCH1	5	.	.	.	.	.	.	+	+	.	.	.
	Adv regen	QUCH2	2	.	.	.	.	.	.	+	+	.	.	.
Quercus emoryi														
	Yng regen	QUEM1	52	.	.	.	.	.	.	+	+	+	+	.
	Adv regen	QUEM2	54	.	.	.	.	.	.	+	+	+	+	.
	Mature	QUEM3	15	.	.	.	.	.	.	.	+	+	+	.

SPECIES NAME		SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
------------------ TREES ------------------		TREE												
Quercus gambelii														
	Yng regen	QUGA1	354	.	.	.	+	+	.	+	+	.	+	+
	Adv regen	QUGA2	370	.	.	.	+	+	.	+	+	+	+	+
	Mature	QUGA3	123	.	.	.	.	+	.	+	+	.	+	.
Quercus grisea														
	Yng regen	QUGR1	20	.	.	.	.	.	.	.	+	.	+	.
	Adv regen	QUGR2	19	.	.	.	.	.	.	.	+	.	+	.
	Mature	QUGR3	10	.	.	.	.	.	.	.	+	.	+	.
Quercus hypoleucoides														
	Yng regen	QUHY1	75	.	.	.	.	.	.	+	+	+	+	.
	Adv regen	QUHY2	70	.	.	.	.	+	.	+	+	+	+	.
	Mature	QUHY3	12	.	.	.	.	.	.	+	+	+	+	.
Quercus muhlenbergia														
	Yng regen	QUMU1	2	.	.	.	.	.	.	.	+	.	.	.
	Adv regen	QUMU2	3	.	.	.	.	.	.	.	+	.	.	.
Quercus rugosa (*Q. reticulata*)														
	Yng regen	QURU1	26	.	.	.	.	+	.	+	+	+	.	.
	Adv regen	QURU2	29	.	.	.	.	.	.	+	+	+	.	.
	Mature	QURU3	1	.	.	.	.	.	.	.	+	.	.	.
Robinia neomexicana														
	Yng regen	RONE1	7	.	.	.	.	+	.	.	+	.	.	.
Salix scouleriana														
	Yng regen	SASC1	11	.	+	+	+	+	.	.	.	.	.	.
	Adv regen	SASC2	8	.	+	+	+	+	.	.	.	.	.	.
	Mature	SASC3	1	.	.	.	+	.	.	.	.	.	.	.
---------------- SHRUBS ----------------		SHRUBS												
Acer glabrum		ACGL	241	.	+	+	+	+	.	+	+	.	.	+
Acer grandidentatum		ACGR	42	.	.	.	.	+	.	+	+	.	.	+
Acer negundo		ACNE	17	.	.	.	+	+	.	+	+	.	.	+
Agave spp.		AGAVE	6	.	.	.	.	.	.	+	+	.	+	.
Agave chrysantha		AGCR	1	.	.	.	.	.	.	.	+	.	.	.
Agave palmeri		AGPAL	6	.	.	.	.	.	.	.	+	.	+	.
Agave parryi		AGPAR	30	.	.	.	.	.	.	+	+	+	+	.
Alnus spp.		ALNUS	7	.	.	+	+	.	.	.	+	.	.	.
Alnus oblongifolia		ALOB	11	.	.	.	+	+	.	.	+	.	.	+
Alnus tenuifolia		ALTE	13	.	+	+	+	+	.	+	.	.	.	+
Amelanchier alnifolia		AMAL	117	.	+	+	+	+	.	+	+	.	.	.
Amelanchier goldmannii		AMGO	1	.	.	.	+	.	.	.	.	.	.	.
Amelanchier utahensis (Incl: *A. oreophila; A. mormonica*)		AMUT	45	.	+	+	+	+	.	+	+	.	.	.
Amorpha canescens		AMCA	15	.	.	.	.	.	.	+	+	.	.	.
Amorpha fruticosa		AMFR	4	.	.	.	.	.	.	+	+	.	.	.
Arbutus arizonica		ARBAR	9	.	.	.	.	.	.	.	+	.	.	.
Arctostaphylos pringlei		ARPR	32	.	.	.	.	.	.	+	+	.	+	.
Arctostaphylos pungens		ARPU	64	.	.	.	.	.	.	+	+	.	+	.
Arctostaphylos uva-ursi		ARUV	99	.	.	+	+	+	+	+	+	.	.	.
Artemisia arbuscula		ARARB	6	.	.	.	.	.	.	.	+	.	.	.
Artemisia tridentata		ARTR	27	.	.	.	.	.	.	.	+	.	.	.
Baccharis thesioides		BATH	6	.	.	.	.	.	.	+	+	+	.	.
Berberis fendleri		BEFE	23	.	.	.	+	+	.	+	+	.	.	.

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 0 0 0 0 0 0 0 0 0 1 1 / 1 2 3 4 5 6 7 8 9 0 1
---------------- SHRUBS ----------------	**SHRUBS**		
Berberis fremontii (*Mahonia fremontii*)	MAFR	1	. . . . + ...
Berberis haematocarpa (*Mahonia haematocarpa*)	MAHA	1	. . . . + . . .
Berberis repens (*Mahonia repens*)	BERE	370	. + + + + . + + . . .
Bouvadia glaberrima	BOGL	2	. . . . + + .
Brickellia californica	BRICA	2	. . . . + . . .
Carphochaete bigelovii	CABI	15	. . . . + + + .
Ceanothus fendleri	CEFE	350	. . . + + . + + + + .
Ceanothus greggii	CEGR	6	. . . . + + + .
Cercocarpus montanus	CEMO	204	. . . . + . + + + + .
Chimaphila umbellata	CHUM	58	. + + + + . + . . . +
Chrysothamnus spp.	CHRYSO	3	. . . . + . . .
Chrysothamnus depressus	CHDE	10	. . . . + . . .
Chrysothamnus greenei	CHGR	3	. . . . . . + + . . .
Chrysothamnus nauseosus	CHNA	44	. . . . . . + + . . .
Chrysothamnus viscidiflorus	CHVI	52	. . . . + . + + . . .
Clematis columbiana (*C. pseudoalpina*)	CLCO	225	+ + + + + . + + . . .
Clematis hirsutissima	CLHI	10	. . . . . . + + . . .
Clematis ligusticifolia	LLI	39	. . . + + . + + . . +
Cowania mexicana	COWME	6	. . . . + . . .
Dalea formosa	DAFO	1	. . . . + . . .
Dalea leporina	DALE	2	. . . . + . + .
Dalea wislizeni	DAWI	2	. . . . + .
Dasylirion wheeleri	DAWH	1	. . . . + .
Fallugia paradoxa	FAPA	15	. . . . + + . .
Fendlera rupicola	FERU	25	. . . . + . + + . + .
Forestiera neomexicana	FONE	5	. . . . + . . .
Fraxinus spp.	FRAXIN	1	. . . . . . + ...
Fraxinus anomala	FRAN	2	. . . . + . . + . . .
Fraxinus pennslvanica	FRPE	21	. . . . + . + + . + .
Fraxinus velutina	FRVE	16	. . . . + . + + . . +
Garrya flavescens	GAFL	3	. . . . + . . .
Garrya wrightii	GAWR	86	. . . . + . + + + + .
Gaultheria humifusa	GAHU	1	. . + ...
Gutierrezia microcephala (Incl: *G. lucida*)	GULU	13	. . . . + . .
Gutierrezia sarothrae (*Xanthocephalum sarothrae*)	GUSA	75	. . . . . . + + . . .
Holodiscus dumosus	HODU	183	+ + + + + + + + . . +
Hymenoxys acaulis	HYAC	44	+ . . . + . + + . . .
Hymenoxys richardsonii	HYRI	130	. . . . + . + + . . .
Hymenoxys rusbyi	HYRU	3	. . . . + . . .
Jamesia americana	JAAM	90	. + + + + + + + . . +
Juglans major	JUMA	33	. . . . + . + + + + +
Juniperus communis	JUCO	255	+ + + + + + + + . . .
Juniperus deppeana	JUDE	93	. . . . + . + + + + .
Juniperus osteosperma	JUOS	9	. . . + . . . + . . .
Juniperus scopulorum	JUSC	11	. . . + + . + + . . .
Linnaea borealis	LIBO	56	. + + + + ...
Lonicera spp.	LONICE	12	. . . + + . + + . . .
Lonicera albiflora	LOAL	9	. . . . + . + + . . .
Lonicera arizonica	LOAR	110	. + + + + . + + + + +

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO.										
			01	02	03	04	05	06	07	08	09	10	11
---------------- SHRUBS ----------------	SHRUBS												
Lonicera involucrata	LOIN	182	.	+	+	+	+	.	+	.	.	.	.
Lonicera utahensis	LOUT	94	.	+	+	+	+	.	+	+	.	.	.
Lycium spp.	LYCIUM	2	.	.	.	.	+	.	.	+	.	.	.
Mimosa biuncifera	MIBI	5	.	.	.	.	.	.	.	+	.	+	.
Mimosa grahamii	MIGR	2	.	.	.	.	.	.	.	+	.	+	.
Nolina microcarpa	NOMI	50	.	.	.	.	.	.	+	+	+	+	.
Nolina texana	NOTE	1	.	.	.	.	.	.	.	+	.	.	.
Opuntia spp.	OPUNTI	75	.	.	.	.	+	.	+	+	.	+	.
Opuntia engelmannii	OPEN	18	.	.	.	.	.	.	.	+	.	+	.
(*Opuntia phaeacantha*)													
Opuntia imbricata	OPIM	3	.	.	.	.	.	.	.	+	.	.	.
Opuntia plumbea	OPPL	26	.	.	.	.	.	.	.	+	.	+	.
Opuntia polyacantha	OPPO	24	.	.	.	.	.	.	+	+	.	.	.
Opuntia spinosior	OPSP	8	.	.	.	.	.	.	.	+	.	+	.
Opuntia whiplei	OPWH	1	.	.	.	.	.	.	.	+	.	.	.
Pachistima myrsinites	PAMY	293	+	+	+	+	+	+	+	+	.	.	.
Parthenocissus inserta	PAIN	6	.	.	.	.	+	.	.	.	.	.	+
Philadelphus spp.	PHILA	6	.	.	.	+	+	.	+	.	.	.	+
Philadelphus microphyllus	PHMI	5	.	.	.	.	+	.	+	.	.	.	.
Physocarpus monogynus	PHMO	76	+	+	+	+	+	.	+	+	.	.	+
Pinus edulis – shrubs	PIED	4	.	.	.	.	+	.	+	.	.	.	.
Platanus wrightii	PLWR	3	.	.	.	.	.	.	.	.	+	+	.
Poliomintha incana	POINC	1	.	.	.	.	.	.	.	+	.	.	.
Populus angustifolia	POAN	2	.	.	.	+	.	.	+	.	.	.	.
Populus tremuloides – shrubs	POTR	374	+	+	+	+	+	+	+	+	.	.	.
Potentilla fruticosa	PEFL	17	+	+	.	+	+	.	+	+	.	.	.
(*Pentaphylloides floribunda*)													
Prunus spp.	PRUNUS	7	.	.	.	.	+	.	+	+	.	+	.
Prunus emarginata	PREM	10	.	+	.	.	+	.	+	.	.	.	.
Prunus serotina ssp. virens	PRSE	28	.	.	+	+	+	.	+	+	.	+	.
(*P. virens*)													
Prunus virginiana	PRVI	116	.	+	+	+	+	.	+	+	.	.	+
Ptelea trifoliata	PTTR	23	.	.	.	.	+	.	+	+	+	+	+
Purshia tridentata	PUTR	12	.	.	.	.	.	.	+	+	.	.	.
Quercus arizonica	QUAR	133	.	.	.	.	.	.	+	+	+	+	.
Quercus chrysolepis	QUCH	20	.	.	.	.	.	.	+	+	.	.	.
(*Q. palmeri; Q. willcoxii*)													
Quercus emoryi	QUEM	86	.	.	.	.	.	.	+	+	+	+	.
Quercus gambelii	QUGA	933		+	+	+	+	.	+	+	+	+	+
Quercus grisea	QUGR	87	.	.	.	.	.	.	+	+	.	+	.
Quercus hypoleucoides	QUHY	124	.	.	.	.	+	.	+	+	+	+	+
Quercus muhlenbergii	QUMU	2	.	.	.	.	.	.	.	+	.	.	.
Quercus rugosa	QURU	80	.	.	.	.	+	.	+	+	+	+	+
Quercus toumeyi	QUTO	6	.	.	.	.	.	.	.	+	+	+	.
Quercus turbinella	QUTU	24	.	.	.	.	.	.	.	+	.	+	.
Quercus undulata	QUUN	67	.	.	.	.	+	.	+	+	.	.	.
(*Q. gambelii x Q. grisea*)													
Rhamnus betulaefolia	RHBE	51	.	.	.	.	+	.	+	+	+	+	+
Rhamnus californica	RHCA	4	.	.	.	.	.	.	+	+	.	.	.
Rhamnus crocea	RHCR	14	.	.	.	.	.	.	.	+	.	.	.
Rhus spp.	RHUS	2	.	.	.	.	.	.	.	+	.	.	.
Rhus aromatica	RHAR	120	.	.	.	.	+	.	+	+	+	+	+
(*R. trilobata*)													
Rhus choriophylla	RHCH	5	.	.	.	.	.	.	+	.	.	+	.
Rhus glabra	RHGL	5	.	.	.	.	+	.	.	+	.	.	+

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 01 02 03 04 05 06 07 08 09 10 11
---------------- SHRUBS ----------------	SHRUBS		
Ribes spp.	RIBES	85	. + + + + . + + . . +
Ribes aureum	RIAU	2	. . . . . . + ...
Ribes cereum	RICE	107	+ + + + + . + + . . .
Ribes inerme	RIIN	56	+ + . + + . + + . . .
Ribes lacustre	RILA	1	. . + ...
Ribes leptanthum	RILE	9	. . + . + . . + . . .
Ribes montigenum	RIMO	148	+ + + + + . + ...
Ribes pinetorum	RIPI	77	. + + + + . + + . . .
Ribes viscosissimum	RIVI	1	. . . . + ...
Ribes wolfii	RIWO	93	. + + + + . + ...
Robinia neomexicana	RONE	290	. + + + + . + + + + +
Rosa spp.	ROSA	391	+ + + + + + + + . . +
Rosa woodsii (*R. fendleri; R. arizonica*)	ROWO	62	+ + . + + . + + . . .
Rubus spp.	RUBUS	1	. . + ...
Rubus arizonensis	RUAR	2	. . . . +
Rubus deliciosus	RUDE	5	. . . . + . + + . . .
Rubus idaeus var. *strigosus* (*R. strigosus*)	RUID	115	+ + + + + . + + . . +
Rubus leucodermis	RULE	7	. . + + + . + ...
Rubus neomexicanus	RUNE	17	. + + + + . + + . . +
Rubus parviflorus	RUPA	214	. + + + + . . + . . .
Salix spp.	SALIX	40	. + + + + ... +
Salix bebbiana (*S. depressa*)	SADE	2	. . . + ...
Salix pseudocordata (*S. myrtillifolia*)	SAPS	1	. . . . + . . .
Salix scouleriana	SASC	104	. + + + + + + ...
Salix subcoerulea (*S. drummondiana*)	SASU	2	. + ... + . . .
Sambucus spp.	SAMBUC	36	. + + + + . + + . . .
Sambucus glauca	SAGL	12	. . + + + . + ...
Sambucus melancarpa	SAME	3	. . + . + ...
Sambucus racemosa	SARA	34	+ + + + . . + ...
Selloa glutinosa	SEGL	3	. . . . . . + . . + .
Shepherdia canadensis	SHCA	94	. + + + + . + + . . .
Sorbus spp.	SORBUS	23	. + + . + ...
Sorbus dumosa	SODU	15	. + + . + ...
Sorbus scopulina	SOSC	9	. + + + + ...
Swida sericea (*Cornus stolonifera*)	COST	48	. + + + + . + + . . .
Symphoricarpos oreophilus	SYOR	438	+ + + + + + + + . . +
Symphoricarpos palmeri	SYPAL	1	. . . . . . + ...
Symphoricarpos parishii	SYPAR	1	. . . . + . . .
Symphoricarpos rotundifolius	SYRO	6	. . . . + . + + . . .
Toxicodendron rydbergii (*Rhus radicans*)	TORY	46	. . . . + . + + . + +
Vaccinium myrtillus (*V. oreophilum; V. caespitosum*)	VAMY	282	+ + + + + . + ...
Vitis arizonica	VIAR	37	. . . . + . + + + + +
Yucca spp.	YUCCA	8	. . . . + . . .
Yucca angustissima	YUAN	2	. . . . + . . + . . .
Yucca baccata	YUBA	66	. . . . + . + + . + .
Yucca glauca	YUGL	28	. . . . . . + + . . .
Yucca schottii	YUSC	44	. . . . . . + + + + .

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO.										
			01	02	03	04	05	06	07	08	09	10	11
-------------- **GRAMINOIDS** --------------	**GRASS**												
Agropyron spp.	AGROPY	16	.	.	.	+	+	.	.	+	.	.	+
Agropyron arizonicum	AGAR	36	.	.	+	+	+	.	+	+	+	.	.
Agropyron desertorum	AGDE	4	.	.	.	.	.	.	.	+	.	+	.
Agropyron elongatum	AGEL	2	.	.	+	.	.	.	.	+	.	.	.
Agropyron smithii	AGSM	23	.	.	.	.	.	.	+	+	.	.	.
Agropyron subsecundum	AGSU	10	+	.	+	.	+	.	+	+	.	.	.
Agropyron trachycaulum	AGTR	26	+	+	+	+	+	.	+	+	.	.	.
Agrostis spp.	AGROST	12	.	+	+	+	+	.	.	+	.	.	.
Agrostis alba	AGGI	9	.	+	+	+	+	.	.	.	.	.	+
(*A. gigantea; A. stolonifera*)													
Agrostis idahoensis	AGID	1	.	+	.	.	.	.	.	.	.	.	.
Agrostis scabra	AGSC	29	.	+	+	+	+	.	+	+	.	.	.
Agrostis semiverticillata	AGSE	1	.	.	.	.	.	.	.	+	.	.	.
Andropogon spp.	ANDROP	25	.	.	.	.	.	.	+	+	.	+	.
Andropogon gerardi	ANGE	44	.	.	.	.	.	.	+	+	.	.	.
Andropogon pseudorepens	ANPS	1	.	.	.	.	.	.	+	.	.	.	.
Aristida spp.	ARISTI	8	.	.	.	.	.	.	+	+	.	+	.
Aristida arizonica	ARAR	107	.	.	.	.	.	.	+	+	+	+	+
Aristida fendleriana	ARFE	62	.	+	+	+	+	.	+	+	.	.	.
Aristida longiseta	ARLO	8	.	.	.	.	.	.	.	+	.	.	.
Aristida orcuttiana	AROR	51	.	.	.	.	.	.	+	+	+	+	.
Aristida wrightii	ARWR	1	.	.	.	.	.	.	.	+	.	.	.
Blepharoneuron tricholepis	BLTR	381	+	.	.	+	+	.	+	+	.	+	+
Bouteloua barbatus	BOBA	3	.	.	.	.	.	.	.	+	.	+	.
Bouteloua curtipendula	BOCU	79	.	.	.	.	.	.	+	+	.	+	.
Bouteloua gracilis	BOGR	323	.	.	.	.	+	.	+	+	.	+	+
Bouteloua hirsuta	BOHI	8	.	.	.	.	.	.	.	+	.	+	.
Bromus spp.	BROMUS	178	+	+	+	+	+	.	+	+	.	.	+
Bromus carinatus	BRCA	54	.	.	.	+	+	.	+	+	.	+	+
Bromus ciliatus	BRCI	909	+	+	+	+	+	+	+	+	.	+	+
(Incl: *Bromopsis* or *Bromus richardsonii*)													
Bromus frondosa	BRFR	14	.	.	.	.	+	.	+	+	.	.	.
(*Bromopsis frondosus*)													
Bromus inermis	BRIN	2	.	.	.	+	.	.	.	+	.	.	.
(*Bromopsis inermis*)													
Bromus japonicus	BRJA	1	.	.	.	.	.	.	.	.	.	.	+
Bromus lanatipes	BRLA	28	.	.	.	+	+	.	+	+	.	.	+
(*Bromopsis lanatipes*)													
Bromus orcuttianus	BROR	1	.	.	.	.	.	.	.	+	.	.	.
Bromus polyanthus	BRPO	33	+	+	.	.	+	.	+	+	+	+	.
Bromus anomalous	BRPOR	19	+	+	+	+	.	.	+	+	.	.	.
(*Bromus porteri*)													
Bromus tectorum	BRTE	24	.	.	.	.	.	.	.	+	.	.	.
Bromus marginatus	CEMA	19	.	.	.	.	+	.	+	+	.	.	.
(*Ceratochloa marginata*)													
Calamagrostis canadensis	CACA	24	.	+	+	+	+	.	.	+	.	.	.
Calamagrostis inexpansa	CAIN	9	.	.	+	.	+	.	.	+	.	.	.
Calamagrostis purpurascens	CAPU	1	+	.	.	.	.	.	.	.	.	.	.
Carex spp.	CAREX	694	+	+	+	+	+	.	+	+	+	+	+
Carex aurea	CARAU	2	.	.	.	.	+	.	.	+	.	.	.
Carex bella	CABE	24	.	+	+	.	+	.	.	.	.	.	.
Carex brevipes	CABR	16	.	+	+	.	+	+	+	.	.	.	.
Carex deweyana	CADE	6	.	+	.	+	+	.	.	+	+	.	.
Carex ebenea	CAEB	2	.	+	.	.	.	.	.	.	.	.	.

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-------------- GRAMINOIDS --------------	GRASS												
Carex elynoides	CAELY	2	+	.	.	.	.	.	.	.	.	.	.
Carex festivella	CAFE	2	.	.	.	+	.	.	.	.	.	.	+
Carex foenea	CAFO	263	.	+	+	+	+	.	+	+	.	+	.
Carex geophila	CAGE	135	.	.	+	.	+	.	+	+	+	+	.
Carex geyeri	CAGEY	49	.	+	+	+	+	.	+	+	.	.	.
Carex heliophila	CAHE	31	.	.	.	+	.	.	+	+	.	.	.
Carex hoodii	CAHO	2	.	.	+	.	.	.	.	+	.	.	.
Carex lanuginosa	CALA	2	.	.	.	+	+	.	.	.	.	.	.
Carex leucodonta	CALE	17	.	+	+	.	.	.	.	+	.	.	.
Carex microptera	CAMI	15	.	+	+	+	+	.	+	.	.	.	.
Carex montanae	CAMO	35	.	.	.	.	+	.	.	+	.	.	.
Carex nova	CANO	1	+	.	.	.	.	.	.	.	.	.	.
Carex norvegica ssp. *stevenii* (*C. media*)	CANOR	6	.	.	+	+	+	.	+	+	.	.	.
Carex occidentalis	CAOC	30	.	.	.	+	+	.	+	+	.	.	+
Carex praegracilis	CAPR	3	.	.	.	.	+	.	.	+	.	.	.
Carex rossii	CARO	548	+	+	+	+	+	+	+	+	.	.	+
Carex rupestris	CARU	1	+	.	.	.	.	.	.	.	.	.	.
Carex scoparia	CASC	1	.	.	.	.	+	.	.	.	.	.	.
Carex scopulorum	CASC2	1	.	.	+	.	.	.	.	.	.	.	.
Carex stenophylla ssp. *eleocharis* (*C. eleocharis*)	CAST	1	.	.	.	.	.	.	.	+	.	.	.
Carex utriculata (*C. rostrata*)	CAUT	2	.	.	.	+	.	.	.	.	.	.	.
Carex vallicola	CAVA	2	.	.	+	.	+	.	.	.	.	.	.
Cyperus spp.	CYPERU	9	.	.	.	.	+	.	+	+	.	+	.
Cyperus fendlerianus	CYFE	15	.	.	.	.	.	.	+	+	.	.	.
Cyperus inflexus (*C. aristatus*)	CYIN	1	.	.	.	.	.	.	+	.	.	.	.
Cyperus rusbyi	CYRU	19	.	.	.	.	.	.	+	+	.	+	.
Dactylis glomerata	DAGL	11	.	.	.	.	+	.	+	+	.	.	.
Danthonia spp.	DANTHO	2	.	.	.	.	+	.	.	.	.	.	.
Danthonia californica	DACA	2	.	.	+	.	+	.	.	.	.	.	.
Danthonia intermedia	DAIN	5	.	.	.	+	+	.	.	+	.	.	.
Danthonia parryi	DAPA	38	+	.	.	+	+	+	+	+	.	.	.
Deschampsia caespitosa	DECA	14	.	+	+	+	.	.	.	+	.	.	.
Dichanthelium lanuginosum (*Panicum huachucae*)	DILA	4	.	.	.	.	.	.	.	+	.	.	.
Elymus spp.	ELYMUS	7	.	.	+	.	+	.	+	+	.	.	.
Elymus ambiguus	ELAM	2	.	.	.	.	+	.	+	.	.	.	.
Elymus canadensis	ELCA	3	.	.	.	.	+	.	.	+	.	.	.
Elymus glaucus	ELGL	40	.	+	+	+	+	.	.	+	.	.	+
Elymus triticoisdes	ELTR	14	.	+	+	+	+	.	.	.	.	.	.
Eragrostis spp.	ERAGRO	2	.	.	.	.	.	.	.	+	.	.	.
Eragrostis intermedia	ERIN	3	.	.	.	.	.	.	.	+	.	+	.
Festuca spp.	FESTUC	6	.	+	+	.	+	.	+	+	.	.	.
Festuca arizonica	FEAR	512	+	+	+	+	+	+	+	+	.	.	.
Festuca ovina (incl: *F. brachyphylla*)	FEBR	23	.	+	+	.	.	.	+	+	.	.	.
Festuca idahoensis	FEID	3	.	+	+	.	.	.	.	.	.	.	.
Festuca octoflora	FEOC	1	.	.	.	.	.	.	.	+	.	.	.
Festuca sororia	FESO	65	.	+	+	+	+	.	+	.	.	.	.
Festuca thurberi	FETH	53	+	+	+	+	+	.	+	+	.	.	.
Glyceria elata	GLEL	5	.	.	.	+	.	.	.	.	.	.	+
Glyceria grandis	GLMA	1	.	.	.	.	.	.	.	.	.	.	+

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-------------- **GRAMINOIDS** --------------	**GRASS**												
Glyceria striata	GLST	8	.	.	.	+	+	.	.	.	.	.	+
Hilaria jamesii	HIJA	1	.	.	.	.	.	.	.	+	.	.	.
Juncus arcticus	JUAR	5	.	.	.	+	.	.	.	+	.	.	.
(*J. balticus*)													
Juncus drummondii	JUDR	1	.	.	+	.	.	.	.	.	.	.	.
Juncus interior	JUIN	2	.	.	.	.	.	.	.	+	.	.	.
Juncus longistylis	JULO	3	.	.	.	+	.	.	.	.	.	.	+
Juncus parryi	JUPA	3	.	+	+	.	.	.	.	.	.	.	.
Juncus saximontanus	JUSA	1	.	.	.	.	.	.	.	+	.	.	.
Koeleria pyramidata	KOPY	908	+	+	+	+	+	+	+	+	+	+	.
(*K. cristata; K. macrantha; K. nitida*)													
Leucopoa kingii	LEKI	1	.	.	.	.	.	.	.	+	.	.	.
Luzula parviflora	LUPA	92	.	+	+	+	+	.	+	+	.	.	.
Luzula spicata	LUSP	1	.	+	.	.	.	.	.	.	.	.	.
Lycurus phleoides	LYPH	26	.	.	.	.	.	.	.	+	.	+	.
Melica porteri	MEPO	16	.	+	.	+	+	.	+	.	.	.	+
Muhlenbergia spp.	MUHLEN	9	.	+	.	.	+	.	+	+	.	.	.
Muhlenbergia dubia	MUDU	17	.	.	.	.	+	.	+	+	.	.	.
Muhlenbergia emersleyi	MUEM	29	.	.	.	.	.	.	.	+	+	+	.
Muhlenbergia fragilis	MUFR	1	.	.	.	.	.	.	.	+	.	.	.
Muhlenbergia glauca	MUGL	2	.	.	.	.	.	.	.	+	.	+	.
Muhlenbergia longiligula	MULO	176	.	.	.	.	+	.	+	+	+	+	.
Muhlenbergia minutissima	MUMI	3	.	.	.	.	.	.	.	+	.	+	.
Muhlenbergia montana	MUMO	597	+	+	+	+	+	.	+	+	.	+	+
Muhlenbergia monticola	MUMO1	3	.	.	.	.	.	.	+	+	.	.	.
Muhlenbergia pauciflora	MUPA	11	.	.	.	.	+	.	+	+	.	.	.
Muhlenbergia pungens	MUPU	1	.	.	.	.	.	.	.	+	.	.	.
Muhlenbergia racemosa	MURA	4	.	.	.	.	.	.	.	+	.	.	.
Muhlenbergia repens	MURE	1	.	.	.	.	.	.	.	+	.	.	.
Muhlenbergia rigens	MURI	25	.	.	.	.	+	.	+	+	.	.	+
Muhlenbergia virescens	MUVI	376	.	+	+	+	+	.	+	+	.	+	+
Muhlenbergia wrightii	MUWR	16	.	.	.	.	.	.	+	+	.	.	+
Oryzopsis spp.	ORYZOP	12	.	.	+	+	+	.	.	.	.	.	.
Oryzopsis asperifolia	ORAS	51	.	+	+	+	+	.	.	.	.	.	.
Oryzopsis hymenoides	ORHY	16	.	.	.	.	.	.	+	+	.	.	.
Oryzopsis micrantha	ORMI	24	+	.	.	+	+	.	+	+	.	+	.
Panicum bulbosum	PABU	50	.	.	.	.	+	.	+	+	+	+	.
Panicum spp.	PANICU	3	.	.	.	.	.	.	.	+	.	.	.
Panicum obtusum	PAOB	1	.	.	.	.	.	.	.	+	.	.	.
Panicum virgatum	PAVI	3	.	.	.	.	.	.	.	+	.	.	.
Phleum commutatum	PHCO	7	.	+	+	+	.	.	.	.	.	.	.
(*P. alpinum*)													
Phleum pratensis	PHPR	7	.	.	.	+	+	.	.	+	.	.	.
Piptochaetium fimbriatum	PIFI	41	.	.	.	.	.	.	+	+	+	+	.
Poa spp.	POA	19	.	+	+	+	+	.	.	+	.	.	.
Poa alpina	POALP	6	+	+	+	.	.	.	.	.	.	.	.
Poa annua	POANN	1	.	.	.	.	+	.	.	.	.	.	.
Poa artica ssp. *grayana*	POAR	1	.	+	.	.	.	.	.	.	.	.	.
Poa compressa	POCO	6	.	.	.	+	.	.	.	+	.	.	+
Poa epilis	POEP	1	.	+	.	.	.	.	.	.	.	.	.
Poa fendleriana	POFE	1166	+	+	+	+	+	+	+	+	+	+	+
Poa fendleriana ssp. *longiligula*	POLON	1	.	.	.	.	.	.	.	+	.	.	.
Poa glauca var. *rupicola*	POGL	3	+	+	+	.	.	.	.	.	.	.	.
(*P. rupicola*)													
Poa leptocoma	POLE	15	.	+	+	+	.	.	+	.	.	.	.

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
-------------- **GRAMINOIDS** --------------	**GRASS**												
Poa nervosa var. *tracyi*	PONE	4	.	.	+	.	+	.	.	+	.	.	.
Poa nemoralis var. *interior* (*P. interior*)	PONEM	20	+	+	+	+	+	.	+	+	.	.	.
Poa palustris	POPA	8	.	.	.	+	.	.	+	.	.	.	+
Poa pratensis	POPR	126	.	+	+	+	+	.	+	+	.	.	+
Poa reflexa	PORE	13	.	+	+	+	.	.	.	.	.	.	.
Poa tracyi (*P. occidentalis*)	POTRA	3	.	.	.	+	+	.	.	.	.	.	.
Schizachne purpurascens	SCPU	8	.	.	.	+	+	.	.	.	.	.	+
Schizachyrium cirratum (*Andropogon cirratus*)	SCCI	26	.	.	.	.	.	.	.	+	.	+	.
Schizachyrium hirtiflorum (*Andropogon hirtiflorus*)	SCHI	1	.	.	.	.	.	.	.	.	.	+	.
Schizachyrium scoparium (*Andropogon scoparius*)	SCSC	170	.	.	.	+	+	.	+	+	.	.	.
Schizachyrium scoparium var. *frequens*	SCSCFR	1	.	.	.	.	.	.	.	.	.	+	.
Schizachyrium scoparium var. *neomexicanum*	SCSCNE	3	.	.	.	.	.	.	.	+	.	+	.
Scirpus microcarpa	SCMI	3	.	.	.	+	.	.	.	.	.	.	+
Setaria spp.	SETARI	1	.	.	.	.	.	.	.	+	.	.	.
Setaria geniculata	SEGE	5	.	.	.	.	.	.	.	+	.	.	.
Setaria grisebachii	SEGR	1	.	.	.	.	.	.	.	.	.	+	.
Sitanion hystrix (*S. longiflorum*)	SIHY	958	+	+	+	+	+	.	+	+	.	+	+
Sorghastrum avenaceum (*S. nutans*)	SOAV	16	.	.	.	.	.	.	+	+	.	.	.
Sporobolus spp.	SPOROB	2	.	.	.	.	.	.	.	+	.	.	.
Sporobolus cryptandrus	SPCR	8	.	.	.	.	.	.	.	+	.	.	.
Sporobolus contractus	SPCO	1	.	.	.	.	.	.	.	+	.	.	.
Sporobolus giganteus	SPGI	1	.	.	.	.	.	.	.	+	.	.	.
Sporobolus interruptus	SPIN	34	.	.	.	.	.	.	.	+	.	+	.
Stipa spp.	STIPA	34	.	.	.	+	+	.	+	+	.	.	.
Stipa columbiana (*S. occidentalis*)	STCO	9	.	.	.	+	+	.	.	+	.	.	.
Stipa comata	STCOM	25	.	.	.	.	.	.	.	+	.	.	.
Stipa lettermanii	STLE	5	.	.	.	.	+	.	+	+	.	.	.
Stipa neomexicana	STNE	1	.	.	.	.	.	.	.	+	.	.	.
Stipa pringlei	STPR	104	.	.	.	+	+	.	+	+	.	+	+
Stipa robusta	STRO	1	.	.	.	.	.	.	.	+	.	.	.
Trisetum spicatum	TRSP	24	+	+	+	.	+	.	.	.	.	.	.
Trisetum spicatum ssp. *montanum* (*T. montanum*)	TRSPMO	220	.	+	+	+	+	.	+	.	.	.	.
Trisetum wolfii	TRWOL	2	.	+	.	.	.	.	.	.	.	.	.
Unknown grass	UNGR	3	.	.	.	.	.	.	.	+	.	.	.
---------------- **FORBS** ----------------	**FORBS**												
Abronia spp.	ABRONI	2	.	.	.	.	.	.	.	+	.	.	.
Achillea millefolium ssp. *lanulosa* (*A. lanulosa*)	ACMI	615	+	+	+	+	+	.	+	+	.	+	+
Acomastylis rossii (*Geum rossii*)	ACRO	8	.	+	+	.	.	.	.	.	.	.	.
Aconitum columbianum	ACCO	15	.	+	+	+	.	.	.	.	.	.	.
Actaea rubra ssp. *arguta* (*A. arguta*)	ACRU	96	.	+	+	+	+	.	.	.	.	.	+
Agastache sp.	AGASTA	2	.	.	.	.	+	.	+	.	.	.	.

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 0 0 0 0 0 0 0 0 0 1 1 / 1 2 3 4 5 6 7 8 9 0 1
----------------- FORBS -----------------	FORBS		
Agastache pallidiflora	AGPA	34	. . . + + . + + . . .
Ageratina herbacea (*Eupatorium herbaceum*)	AGHE	81	. + + + + . + + + + .
Agoseris spp.	AGOSER	9	. . . + + . + + . . .
Agoseris aurantiaca	AGAU	14	. + + + + . . + . . .
Agoseris glauca	AGGL	24	. . + . + . + + . . .
Agrimonia striata	AGST	10	. . + + + . . + . . +
Allium spp.	ALLIUM	29	. + + . + . + + . . .
Allium cernuum	ALCE	154	+ . + + + . + + . . .
Allium geyeri	ALGE	9	+ + + ... + . . .
Allium gooddingii	ALGO	2	. . . . + ...
Allium kunthii	ALKU	4	. . . . + . + .
Allium rhizomatum	ALRH	4	. . . . + . . .
Amaranthus spp.	AMARAN	3	. . . . + . . .
Ambrosia spp.	AMBROS	5	. . . . + . . .
Ambrosia psilostachya	AMPS	18	. . . . + . . .
Anaphalis margaritacea	ANAMA	1	. . + ...
Androsace occidentalis	ANOC	10	. + . + + . + ...
Androsace septentrionalis	ANSE	66	+ . + + + . + + . . .
Anemone spp.	ANEMON	1	. . . + ...
Anemone canadensis	ANCA	1	. . . . + ...
Angelica grayii	ANGR	23	. + + ... + . . .
Antennaria spp.	ANTENN	98	+ + + + + . + + . . .
Antennaria arida	ANAR	3	. . . . . . + . + . .
Antennaria neglecta (*A. marginata*)	ANNE	164	. . . + + . + + . . .
Antennaria parvifolia (*A. aprica*)	ANPA	249	. + + + + . + + . + .
Antennaria rosulata	ANRO	170	+ + + + + + + + . . .
Anthericum torreyi	ANTO	16	. . + . . . + + . + .
Apocynum spp.	APOCYN	43	. + + + + . + + . . .
Apocynum androsaemifolium	APAN	30	. . + + + . + + . . .
Apocynum cannabinum	APCA	1	. . + ...
Aquilegia spp.	AQUILE	35	. + + + + . + + . . .
Aquilegia triternata (*A. barnebyi*)	AQBA	20	. + + + + . + ...
Aquilegia caerulea	AQCA	55	+ + + . + ...
Aquilegia chrysantha	AQCH	34	. + + + + . + . . . +
Aquilegia elegantula	AQEL	151	+ + + + + . + + . . .
Arabis spp.	ARABIS	109	+ . . + + . + + + + +
Arabis fendleri	ARAFE	83	. + + + + + + + . . .
Arabis drummondii	ARDRU	25	+ + . + + . + + . . .
Arabis pendulina	ARPE	1	. . . . + . . .
Arabis tricornuta	ARTRI	2	. . . . + . + .
Aralia spp.	ARALIA	1	. . . . + ...
Aralia nudicaulis	ARNU	1	. . . . + ...
Aralia racemosa	ARRA	1	. . . . + ...
Arctium minus	ARMI	1	. . . . + ...
Arenaria spp.	ARENAR	49	. + + + + . + + . . .
Arenaria eastwoodiae	AREA	6	. . . . . . + + . . .
Arenaria fendleri	AREFE	48	+ + + + + + + + . . .
Arenaria lanuginosa (*A. confusa*)	ARLAN	46	+ + + + + . + + . . .
Arnica spp.	ARNICA	17	. + + + ...
Arnica cordifolia	ARCO	153	+ + + + + . . + . . .

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
----------------- **FORBS** -----------------	**FORBS**												
Arnica latifolia	ARLA	30	.	.	.	+	+	.	+	+	.	.	.
Arnica mollis	ARMO	10	+	+	+	.	.	.	.	.	.	.	.
Artemisia spp.	ARTEMI	4	.	.	.	.	+	.	.	+	.	+	.
Artemisia carruthii	ARCA	209	+	.	+	+	+	.	+	+	.	+	+
Artemisia campestris ssp. *pacifica* (*A. pacifica*)	ARCAM	26	+	.	.	.	.	.	+	+	.	.	.
Artemisia dracunculoides	ARDR	74	.	.	+	.	+	.	+	+	.	.	+
Artemisia franserioides	ARFR	257	+	+	+	+	+	+	+	+	.	.	.
Artemisia frigida	ARFRI	36	+	.	+	+	+	.	+	+	.	.	.
Artemisia ludoviciana	ARLU	415	+	.	.	+	+	.	+	+	+	+	+
Artemisia parryi	ARPAR	1	+	.	.	.	.	.	.	.	.	.	.
Artemisia scopulorum	ARSC	2	.	+	.	.	.	.	.	.	.	.	.
Asclepias spp.	ASCLEP	9	.	.	.	.	.	.	.	+	.	.	+
Asclepias asperula (*A. capricornu*)	ASAS	6	.	.	.	.	.	.	.	+	.	.	.
Asclepias brachystephana	ASBR	8	.	.	.	.	.	.	.	+	.	.	.
Asclepias involucrata	ASIN	2	.	.	.	.	.	.	.	+	.	.	.
Asclepias speciosa	ASSP	1	.	.	.	.	.	.	+	.	.	.	.
Asclepias tuberosa	ASTU	5	.	.	.	.	.	.	.	+	.	+	+
Asclepias viridiflora	ASVI	2	.	.	.	.	.	.	.	+	.	.	.
Asparagus officinalis	ASOF	1	.	.	.	.	.	.	.	+	.	.	.
Aster spp.	ASTER	20	.	.	.	+	+	.	+	+	.	.	.
Aster falcatus (*A. commutatus*)	ASCOM	24	.	.	.	.	.	.	.	+	.	+	.
Aster exilis	ASEX	2	.	.	.	.	.	.	.	+	.	.	.
Aster foliaceus	ASFO	5	.	.	.	+	.	.	+	+	.	.	.
Aster glaucodes	ASGL	7	.	.	.	.	+	.	+	+	.	.	.
Aster laevis	ASLA	6	.	.	.	+	+	.	+	+	.	.	.
Aster praealtus	ASPR	1	.	.	.	.	.	.	.	+	.	.	.
Astragalus spp.	ASTRAG	246	.	.	+	+	+	.	+	+	.	+	.
Astragalus adsurgens	ASAD	2	.	.	.	.	.	.	.	+	.	.	.
Astragalus amphioxys	ASAM	1	.	.	.	.	.	.	.	+	.	.	.
Astragalus cobrensis	ASCO	8	.	.	.	.	.	.	.	+	.	+	.
Astragalus drummondii	ASDR	6	.	.	.	.	.	.	.	+	.	.	.
Astragalus egglestonii	ASEG	6	.	.	.	.	.	.	.	+	.	.	.
Astragalus flexuosus	ASFL	8	.	.	.	+	.	.	+	.	.	.	
Astragalus gilensis	ASGI	31	.	.	.	.	.	.	+	+	.	.	.
Astragalus hallii	ASHA	2	.	.	.	.	.	.	.	+	.	.	.
Astragalus humistratus	ASHU	33	.	.	.	+	+	.	+	+	.	.	.
Astragalus lonchocarpus	ASLO	1	.	.	.	.	.	.	.	+	.	.	.
Astragalus mollisimus	ASMO	7	.	.	.	.	.	.	+	+	.	.	.
Astragalus parryi	ASPA	1	.	.	.	.	.	.	.	+	.	.	.
Astragalus pictiformis	ASPI	1	.	.	.	.	.	.	.	+	.	.	.
Astragalus recurvus	ASRE	3	.	.	.	.	.	.	.	+	.	.	.
Astragalus rusbyi	ASRU	10	.	.	.	.	.	.	+	+	.	.	.
Astragalus tephrodes	ASTE	10	.	.	.	.	+	.	.	+	.	+	.
Astragalus wingatanus	ASWI	1	.	.	.	.	.	.	.	+	.	.	.
Athyrium filix-femina	ATFI	2	.	.	+	+	.	.	.	.	.	.	.
Bahia dissecta	BADI	131	.	.	.	.	+	.	+	+	+	+	+
Balsamorhiza sagittata	BASA	2	.	.	.	.	.	.	.	+	.	.	.
Besseya plantaginea	BEPL	16	.	+	.	+	+	.	+	+	.	.	.
Bidens spp.	BIDENS	7	.	.	.	+	+	.	+	+	.	.	.
Bidens bipinnata	BIBI	5	.	+	+	.	.	.	+	+	.	.	.
Bidens herterosperma	BIHE	3	.	.	.	.	.	.	.	+	.	+	.
Bidens lemmonii	BILE	2	.	.	.	.	.	.	+	+	.	.	.

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
----------------- FORBS -----------------	FORBS												
Bistorta bistortoides	BIBIS	12	.	+	+	+	.	.	.	.	.	.	.
(Polygonum bistortoides)													
Bistorta vivipara	BIVI	13	.	+	+	.	.	.	.	.	.	.	.
(Pologonum viviparum)													
Boerhaavia spp.	BOERHA	1	.	.	.	.	.	.	.	.	.	+	.
Brickellia spp.	BRICKE	78	.	.	.	.	+	.	+	+	+	+	+
Brickellia betonieaefolia	BRBE	12	.	.	.	.	+	.	+	+	.	+	.
Brickellia brachyphylla	BRBR	9	.	.	.	.	.	.	+	+	.	.	.
Brickellia fendleri	BRFE	6	.	.	.	+	+	.	+	+	.	.	.
Brickellia grandiflora	BRGR	95	+	+	.	+	+	.	+	+	.	+	.
Brickellia lemmoni	BRLE	6	.	.	.	.	.	.	.	.	.	+	.
Brickellia microphylla	BRMI	1	.	.	.	.	.	.	.	+	.	.	.
(B. scabra)													
Brickellia rusby	BRRU	1	.	.	.	.	.	.	.	+	.	.	.
Cacalia decomposita	CACDE	4	.	.	.	.	.	.	+	.	.	+	.
Calliandra humilis	CAHU	78	.	.	.	.	.	.	+	+	.	+	.
Calliandra reticulata	CARE	22	.	.	.	.	.	.	.	+	+	+	.
Calliandra schottii	CALSC	3	.	.	.	.	.	.	.	.	+	+	.
Calochortus spp.	CALOCH	3	.	.	.	.	.	.	.	+	.	.	.
Calochortus gunnisonii	CAGU	8	.	.	+	.	.	.	+	+	.	.	.
Calypso bulbosa	CABU	26	.	+	+	.	+	.	+	.	.	.	.
Campanula rotundifolia	CAROT	196	+	+	+	+	+	.	+	+	.	.	+
Cardamine cordifolia	CACO	28	.	+	+	+	+	.	.	+	.	.	+
Castilleja spp.	CASTIL	137	.	+	+	+	+	.	+	+	.	.	.
Castilleja austromontana	CAAU	17	.	+	.	+	+	.	+	+	.	.	.
Castilleja confusa	CACON	4	.	.	.	.	+	.	+	.	.	.	.
Castilleja integra	CAINT	21	.	.	.	.	.	.	+	+	.	.	.
Castilleja lineata	CALI	10	.	.	.	+	+	.	.	+	.	.	.
Castilleja linariafolia	CALI2	18	.	.	.	+	+	.	+	+	.	.	.
Castilleja miniata	CAMIN	33	+	+	+	+	+	.	.	+	.	.	.
Castilleja occidentalis	CASOC	2	+	+	.	.	.	.	.	.	.	.	.
Castilleja rhexifolia	CARH	6	.	+	+	.	.	.	.	.	.	.	.
Castilleja sulphurea	CASU	2	+	.	.	.	+	.	.	.	.	.	.
(C. septentrionalis)													
Cerastium spp.	CERAST	7	.	+	.	+	+	.	+	+	.	.	.
Cerastium arvense	CEAR	5	+	.	+	.	+	.	.	.	.	.	.
Cerastium nutans	CENU	6	.	.	.	+	+	.	+	+	.	.	.
Cerastium texanum	CETE	1	.	.	.	.	+	.	.	.	.	.	.
Chaenactis spp.	CHAENA	2	.		.	.	.	.	.	+	.	.	.
Chaenactis douglasii	CHDO	6	.	.	.	.	.	.	+	+	.	.	.
Chamaesyce fendleri	CHAFE	6	.	.	.	.	.	.	.	+	.	.	.
(Euphorbia fendleri)													
Chamaesyce albomarginata	CHAMAL	1	.	.	.	.	.	.	.	+	.	.	.
(Euphorbia albomarginata)													
Chamerion angustifolium	CHAN	198	+	+	+	+	+	.	+	+	.	.	.
(Epilobium angustifolium)													
Chamaepericlymenum canadense	CHCA	2	.	.	.	+	.	.	.	+	.	.	.
(Cornus canadensis)													
Chamaesaracha coronopus	CHCO	1	.	.	.	.	.	.	.	+	.	.	.
Chamaebatiaria millefolium	CHMI	1	.	.	.	.	.	.	.	+	.	.	.
Chaptalia alsophila	CHALS	38	.	+	.	+	+	.	+	+	.	.	.
Cheilanthes spp.	CHEILA	8	.	.	.	.	.	.	+	+	.	.	.
Cheilanthes fendleri	CHFE	40	.	.	.	.	+	.	+	+	+	+	.
Chenopodium spp.	CHENOP	19	.	.	.	+	+	.	+	+	.	.	+
Chenopodium aff album	CHAL	53	.	.	.	+	+	.	+	+	.	.	.

			SERIES NO.										
SPECIES NAME	SPECIES CODE	NO OF OBS	01	02	03	04	05	06	07	08	09	10	11
---------------- FORBS ----------------	FORBS												
Chenopodium fremontii	CHFR	8	.	.	.	+	+	.	+	+	.	+	.
Chenopodium graveolens	CHIN	15	.	.	.	.	.	.	+	+	.	.	.
Chenopodium leptophyllum	CHLE	1	.	.	.	.	.	.	.	+	.	.	.
Chimaphila menziesii	CHME	3	.	.	.	.	+	.	+	.	.	.	.
Cicuta douglasii	CIDO	4	.	.	.	+	+	.	.	.	.	.	+
(*C. maculata*)													
Circaea alpina	CIAL	7	.		+	+	.	.	.	.	.	.	+
Cirsium spp.	CIRSIU	358	+	+	+	+	+	.	+	+	+	.	.
Cirsium arizonicum	CIAR	11	.	.	.	.	+	.	+	+	.	.	.
Cirsium canescens	CICA	6	.	.	.	.	.	.	+	+	.	.	.
Cirsium calcareum	CICAL	4	.	.	.	.	.	.	.	+	.	.	.
(*C. pulchellum*)													
Cirsium grahami	CIGR	1	.	.	.	.	.	.	.	+	.	.	.
Cirsium parryi	CIPA	36	.	+	+	+	+	.	+	+	.	.	.
Cirsium pallidum	CIPAL	1	.	.	+	.	.	.	.	.	.	.	.
Cirsium pulchellum	CIPU	3	.	.	.	.	.	.	.	+	.	.	.
Cirsium rothrockii	CIRO	1	.	.	.	.	.	.	+	.	.	.	.
Cirsium scopulorum	CISC	2	+	+	.	.	.	.	.	.	.	.	.
Cirsium undulatum	CIUN	3	.	.	.	.	.	.	.	+	.	.	.
Cirsium wheeleri	CIWH	15	.	.	.	.	.	.	+	+	.	.	.
Cirsium wrightii	CIWR	11	.	.	.	+	.	.	.	+	.	.	.
Clementsia rhodantha	CLRH	3	.	+	.	.	.	.	.	.	.	.	.
(*Sedum rhodanthum*)													
Cologania spp.	COLOGA	1	.	.	.	.	.	.	.	+	.	.	.
Cologania longifolia	COLO	110	.	.	.	.	+	.	+	+	+	+	.
(*C. angustifolia*)													
Cologania pulchella	COPU	7	.	.	.	.	.	.	+	+	.	+	.
Comandra umbellata ssp. *pallida*	COUM	78	.	.	.	+	+	.	+	+	.	+	.
(*C. pallida*)													
Commelina spp.	COMMEL	2	.	.	.	.	.	.	.	+	+	.	.
Commelina dianthifolia	CODI	35	.	.	.	.	+	.	+	+	.	+	.
Commelina erecta	COER	1	.	.	.	.	.	.	.	+	.	.	.
Conioselinum scopulorum	COSCO	1	.	.	.	.	+	.	.	.	.	.	.
Conopholis mexicana	COME	24	.	.	.	.	+	+	.	+	.		
Conyza canadensis	CONCA	1	.	.	.	.	.	.	.	+	.	.	.
Conyza schiedeana	COSC	8	.	.	.	.	+	.	.	+	.	.	.
Corallorhiza spp.	CORALL	28	.	+	+	+	+	.	+	+	.	.	.
Corallorhiza maculata	COMA	100	.	+	+	+	+	.	+	+	.	.	+
Corallorhiza striata	COSTR	17	.	+	.	+	+	.	+	+	.	.	.
Corallorhiza trifida	COTR	2	.	.	+	.	.	.	.	.	.	.	.
Corallorhiza wisteriana	COWI	4	.	.	.	.	+	.	+	.	.	.	.
Coreopsis lanceolata	COLA	1	.	.	.	.	.	.	.	+	.	.	.
Corydalis aurea	COAU	1	.	.	+	.	.	.	.	.	.	.	.
Corydalis caseana	COCAS	2	.	+	+	.	.	.	.	.	.	.	.
Cosmos spp.	COSMOS	1	.	.	.	.	.	.	+	.	.	.	.
Cosmos bipinnatus	COBI	2	.	.	.	.	.	.	.	+	.	.	.
(*C. parviflorus*)													
Cosmos parviflora	COPA	3	.	.	.	.	.	.	+	+	.	.	.
Crepis spp.	CREPIS	2	.	.	.	.	+	.	.	+	.	.	.
Crotalaria pumila	CRPU	1	.	.	.	.	.	.	.	+	.	.	.
Cruciferae spp.	CRUCIF	6	.	.	.	.	.	.	+	.	.	.	.
Cryptogramma crispa	CRCR	2	.	.	+	.	+	.	.	.	.	.	.
Cryptantha jamesii	CRJA	31	.	.	.	.	.	.	+	+	.	.	.
Cryptantha thyrsiflora	CRTH	3	.	.	.	.	.	.	+	+	.	.	.
Crypthantha sp.	CRYPTH	1	.	.	.	.	.	.	.	+	.	.	.

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---------------- **FORBS** ----------------	**FORBS**												
Cucurbita foetidissima	CUFO	1	.	.	.	.	.	.	.	+	.	.	.
Cynoglossum officinale	CYNOGL	4	.	.	.	+	.	.	.	.	.	.	.
Cypripedium calceolus	CYCA	1	.	.	.	+	.	.	.	.	.	.	.
Cystopteris fragilis	CYFR	134	+	+	+	+	+	.	+	+	.	.	+
Dalea spp.	DALEA	3	.	.	.	.	.	.	.	+	.	+	.
Dalea candida (*Petalostemon cadidimum*)	DACAN	16	.	+	.	+	.	.	.	+	.	.	.
Dalea filiformis	DAFI	3	.	.	.	.	.	.	.	+	.	.	.
Dalea frutescens	DAFR	1	.	.	.	.	.	.	.	+	.	.	.
Dalea ordiae	DAOR	2	.	.	.	.	.	.	.	+	.	.	.
Dalea polygonoides	DAPO	7	.	.	.	.	.	.	.	+	.	.	.
Delphinium spp.	DELPHI	3	.	.	.	+	+	.	.	+	.	.	.
Delphinium barbeyi	DEBA	31	.	+	+	.	.	.	.	+	.	+	.
Descurainia spp.	DESC	3	.	.	+	+	.	.	.	.	.	.	.
Descurainia richardsonii	DERI	12	+	.	.	+	+	.	+	+	.	.	.
Desmodium spp.	DESMOD	6	.	.	.	.	.	.	+	+	.	+	.
Desmodium arizonicum	DEAR	2	.	.	.	.	.	.	.	.	.	+	
Desmodium cf. *cinerascens*	DECI	1	.	.	.	.	.	.	.	+	.	.	.
Desmanthus cooleyi	DECO	5	.	.	.	.	.	.	.	+	.	.	.
Desmodium grahami	DEGR	9	.	.	.	.	.	.	.	+	.	+	.
Desmodium rosei	DERO	12	.	.	.	.	.	.	.	+	+	+	.
Disporum trachycarpum	DITR	55	.	+	+	+	+	.	+	.	.	.	.
Dithyrea wislizeni	DIWI	1	.	.	.	.	.	.	.	+	.	.	.
Dodecatheon ellisiae	DOEL	2	.	.	+	+	.	.	.	.	.	.	.
Dodecatheon pulchellum	DOPU	1	.	.	+	.	.	.	.	.	.	.	.
Draba spp.	DRABA	57	+	+	+	+	+	.	+	+	.	+	.
Draba asprella	DRAS	24	.	.	.	.	.	.	+	+	.	.	.
Draba aurea	DRAU	32	+	+	+	+	+	.	+	+	.	.	.
Draba helleriana	DRHE	92	.	+	+	+	+	.	+	+	.	.	+
Draba smithii	DRSM	1	+	.	.	.	.	.	.	.	.	.	.
Draba spectabilis	DRSP	2	+	.	.	.	.	.	+	.	.	.	.
Draba streptocarpa	DRST	19	.	+	+	+	+	+	+	+	.	.	.
Drymocallis fissa (*Potentilla fissa*)	DRFIS	10	+	.	.	.	.	+	+	+	.	.	.
Drymaria tenella	DRTE	3	.	.	.	+	.	.	.	+	.	+	.
Dryopteris filix-mas	DRFI	3	.	.	.	.	+	.	.	.	.	.	+
Dugaldia hoopesii (*Helenium hoopsii*)	DUHO	117	.	+	+	+	+	.	+	+	.	.	.
Echinocactus spp.	ECHINC	4	.	.	.	.	.	.	.	+	.	+	.
Echinocereus fendleri	ECFE	1	.	.	.	.	.	.	.	+	.	.	.
Echinocereus spp.	ECHINO	44	.	.	.	.	+	.	+	+	.	+	.
Echinocerus triglochidiatus	ECTR	1	.	.	.	.	.	.	.	.	.	+	.
Echinocereus viridiflorus	ECVI	2	.	.	.	.	.	.	.	+	.	.	.
Epilobium spp.	EPILOB	19	.	.	+	+	+	.	.	+	.	.	.
Epilobium adenocaulon	EPAD	6	.	.	.	+	.	.	.	+	.	.	+
Epilobium ciliatum (*E. glandulosum*)	EPCI	3	.	+	+	.	.	.	.	.	.	.	.
Epilobium hornemannii	EPHO	8	.	+	+	.	.	.	.	.	.	.	.
Epilobium paniculatum	EPPA	2	.	.	.	.	.	.	.	+	.	.	.
Equisetum spp.	EQUISE	13	.	.	.	+	.	.	.	.	.	.	+
Equisetum arvense	EQAR	18	.	+	+	+	+	.	.	+	.	.	+
Equisetum hymale (*Hippochaete hymalis*)	HIHY	6	.	.	.	+	+	.	.	+	.	.	.
Equisetum laevigatum (*Hippochaete laevigata*)	HILA	3	.	.	.	.	+	.	.	+	.	.	+

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 01 02 03 04 05 06 07 08 09 10 11
----------------- FORBS -----------------	FORBS		
Erigeron spp.	ERIGER	292	+ + + + + . + + . . +
Erigeron canus	ERCAN	1	. . . . + . . .
Erigeron concinnus	ERCO	24	. + + ... + . . .
Erigeron compositus	ERCOM	2	+ + ...
Erigeron coulteri	ERCOU	14	. + + ...
Erigeron divergens	ERDI	114	. . . . + . + + . + .
Erigeron elatior	EREL	1	. . + ...
Erigeron eximius (*E. superbus*)	EREX	427	+ + + + + . + + . . .
Erigeron flagellaris	ERFL	233	+ + . + + . + + . . +
Erigeron formosissimus	ERFO	110	. + . + + . + + . . .
Erigeron caespitosus	ERICA	1	. . . . + . . .
Erigeron macranthus	ERMA	76	. . + + + . + + . . .
Erigeron melanocephalus	ERME	4	. + ...
Erigeron neomexicanus (*E. delphinifolius*)	ERNE	78	. . . . + . + + + + .
Erigeron nudiflorus	ERNU	44	. . . . + . + .
Erigeron oreophilus	EROR	4	. . . . . . + + . + .
Erigeron peregrinus	ERPE	32	. + + . + ...
Erigeron platyphyllus	ERPL	89	. + . + + . + + . . .
Erigeron rusbyi	ERRU	10	. . . . + . + + . . .
Erigeron speciosus (*E. macranthus*)	ERSP	44	. + + + + . + + . . .
Erigeron subtrinervis	ERSUB	95	+ . + + + . + + . . .
Erigeron vetensis	ERVE	10	+ + + . . + . + . . .
Eriogonum spp.	ERIOGO	66	. . . + + . + + . . .
Eriogonum alatum	ERAL	135	. . . . + . + + . . .
Eriogonum annuum	ERAN	1	. . . . + . . .
Eriogonum bakeri (*E. jamesii* var. *flavescens*)	ERBA	7	. . . . + . . + . . .
Eriogonum hieracifolium	ERHI	1	. . . . + . . .
Eriogonum jamesii	ERJA	86	+ . . . + . + + . . .
Eriogonum microthecum	ERMI	3	. + ... + . . .
Eriogonum pharnaceoides	ERPH	4	. . . . + . + .
Eriogonum racemosum	ERRA	199	. . . + + . + + . . .
Eriogonum umbellatum	ERUM	8	. . . . + . . .
Eriogonum wrightii	ERWR	5	. . . . + . + .
Erysimum spp.	ERYSIM	3	+ . . . .
Erysimum asperum	ERAS	4	. . . . + . . .
Erysimum capitatum	ERCA	83	+ . + + + . + + . . .
Erythronium grandiflorum	ERGR	8	. + + ...
Euphorbia spp.	EUPHOR	42	. . . + + . + + . + +
Euphorbia albomarginata	EUAL	1	. . . . + . . .
Euphorbia brachycera	EUBR	9	. . . . . . + + + + .
Euphorbia chamaesula	EUCH	9	. . . . . . + + . . .
Euphorbia fendleri	EUFE	3	. . . . + . . .
Euphorbia lurida	EULU	86	. . . . + . + + . . .
Euphorbia palmeri	EUPA	17	. . . + + . + + . . .
Euphorbia revoluta	EURE	1	. . . . + .
Euphorbia robusta	EURO	6	. . . . + . + + . . .
Fragaria americana (*F. vesca* var. *bracteata*)	FRAM	322	+ + + + + . + + . . +
Fragaria ovalis (*F. virginiana* var. *glauca*)	FROV	578	+ + + + + + + + . . +
Frasera spp.	FRASE	11	. . + + + . + + . . .

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
---------------- **FORBS** ----------------	**FORBS**												
Frasera speciosa	FRSP	99	.	+	+	+	+	+	+	+	.	.	+
(*Swertia radiata*)													
Gaillardia spp.	GAILLA	1	.	.	.	.	.	.	.	+	.	.	.
Gaillardia aristata	GAAR	1	.	.	.	.	.	.	.	+	.	.	.
Gaillardia pinnatifida	GAPI	1	.	.	.	.	.	.	.	+	.	.	.
Galactia wrightii	GALWR	3	.	.	.	.	.	.	+	+	.	.	.
Galium spp.	GALIUM	60	.	+	+	+	+	.	+	+	.	+	+
Galium aparine	GAAP	11	.	.	.	+	+	.	+	+	.	.	.
Galium asperrimum	GAAS	46	.	.	.	+	+	.	+	+	+	+	+
Galium boreale	GABO	117	+	+	+	+	+	.	+	+	.	.	.
Galium fendleri	GAFE	48	.	.	.	+	+	.	+	+	+	+	.
Galium microphyllum	GAMI	20	.	.	.	.	+	.	+	+	.	+	.
Galium rothrockii	GARO	6	.	.	.	.	.	.	+	+	.	+	.
Galium tinctorium	GATI	5	.	.	.	.	.	.	+	+	.	+	.
Galium triflorum	GATR	81	.	+	+	+	+	.	+	+	.	.	+
Galium trifidum	GATR2	45	.	.	+	+	+	.	+	+	.	.	.
Galium wrightii	GAWR1	3	.	.	.	.	.	.	.	+	.	.	.
Gaura spp.	GAURA	2	.	.	.	.	.	.	.	+	.	.	.
Gaura hexandra	GAGR	13	.	.	.	.	.	.	.	+	.	.	+
(*G. gracilis*)													
Gaura neomexicana	GANE	1	.	.	.	.	.	.	.	+	.	.	.
Gayophytum diffusum ssp. *parviflorum*	GADI	1	.	.	.	.	.	.	.	+	.	.	.
(*G. nuttans*)													
Gayophytum ramossimum	GARA	4	.	.	.	.	.	.	.	+	.	.	.
Gentiana spp.	GENTIA	9	.	+	+	+	.	.	.	+	.	.	.
Gentiana bigelovii	GEBI	6	.	.	.	.	+	.	+	.	.	.	.
(*Pneumonanthe affinis*)													
Gentiana parryi	PNCA	4	.	.	+	+	.	.	.	.	.	.	.
(*Pneumonanthe calycosa*)													
Gentianella amarella	GEAM	2	.	.	.	+	+	.	.	.	.	.	.
Gentianella amarella ssp. *acuta*	GEAMAC	43	.	+	+	+	+	.	+	+	.	.	.
(*Gentiana strictiflora*)													
Gentianella amarella ssp. *heterosepala*	GEAMHE	23	.	+	+	+	+	.	.	.	.	.	.
(*Gentiana heterosepala*)													
Gentianella microcalyx	GEMI	2	.	.	.	.	.	.	.	.	+	+	.
(*Gentiana microcalyx*)													
Geranium spp.	GERANI	185	.	+	+	+	+	.	+	+	.	.	+
Geranium caespitosum	GECA	366	+	+	+	+	+	+	+	+	+	+	+
Geranium ereophilum	GEER	12	.	.	.	.	.	.	+	+	.	.	.
Geranium richarsonii	GERI	447	+	+	+	+	+	.	+	+	.	.	+
Geum triflorum	ERTR	1	.	.	.	+	.	.	.	.	.	.	.
(*Erythrocoma triflora*)													
Geum aleppicum ssp. *strictum*	GEAL	7	.	.	+	+	.	.	.	.	.	.	+
(*G. strictum*)													
Geum macrophyllum	GEMA	3	.	+	+	+	.	.	.	.	.	.	.
Gilia spp.	GILIA	59	.	.	.	.	+	.	+	+	.	.	.
Gilia macombii	GIMA	2	.	.	.	.	.	.	+	.	.	+	.
Gilia multiflora	GIMU	13	.	.	.	.	.	.	+	+	.	+	.
Gilia pinnatifida var. *calcarea*	GIPI	9	.	.	.	.	+	+	+	+	.	.	.
Gilia polyantha	GIPO	4	.	.	.	.	.	.	.	+	.	.	.
Gnaphalium spp.	GNAPHA	36	.	.	.	.	+	.	+	+	.	+	.
Gnaphalium arizonicum	GNAR	13	.	.	.	.	.	.	+	+	.	+	.
Gnaphalium chilense	GNCH	1	.	.	.	.	.	.	.	.	.	+	.
Gnaphalium pringlei	GNPR	3	.	.	.	.	.	.	.	+	.	+	.
Gnaphalium viscosum	GNVI	19	.	+	+	.	+	.	+	+	.	.	.
(*G. macounii*)													

SPECIES NAME	SPECIES CODE	NO OF OBS	01	02	03	04	05	06	07	08	09	10	11
FORBS	**FORBS**												
Gnaphalium wrightii	GNWR	16	.	+	.	.	.	.	.	+	.	+	.
Goodyera oblongifolia	GOOB	256	.	+	+	+	+	.	+	.	.	.	.
Goodyera repens	GORE	29	.	+	+	+	+	.	.	.	.	.	.
Grindelia spp.	GRINDE	1	.	.	.	.	.	.	.	+	.	.	.
Gutierrezia glutinosa	GUGL	2	.	.	.	.	.	.	.	.	.	+	.
Habenaria spp.	HABENA	16	.	+	+	+	+	.	.	.	.	.	.
Habenaria hyperborea	HAHY	2	.	+	+	.	.	.	.	.	.	.	.
(*Limorchis hyperboreal*)													
Habenaria saccata	HYSA	3	.	+	+	.	.	.	.	.	.	.	.
(*Limorchis saccata*)													
Habenaria sparsiflora	HASP	4	.	.	+	.	.	.	+	+	.	.	.
Habenaria unalascensis	PIUN	1	.	.	.	.	.	.	.	+	.	.	.
(*Piperia unalascensis*)													
Hackelia spp.	HACKEL	4	.	.	.	+	+	.	.	+	.	.	.
Hackelia floribunda	HAFL	6	.	.	.	+	+	.	+	+	.	.	.
Hackelia ursina	HAUR	10	.	.	.	+	+	.	.	.	.	.	.
Halenia recurva	HARE	12	.	+	.	+	.	.	+	+	.	.	.
Haploppappus spp.	HAPLOP	2	.	.	.	.	.	.	+	+	.	.	.
Harbouria trachypleura	HATR	19	.	.	.	.	.	.	+	+	.	.	.
Hedeoma spp.	HEDEOM	18	.	.	.	.	+	.	+	+	.	.	.
Hedeoma costatum	HECO	1	.	.	.	.	.	.	.	+	.	.	.
Hedeoma dentatum	HEDE	7	.	.	.	.	.	.	.	+	.	+	.
Hedeoma diffusum	HEDI	3	.	.	.	.	+	.	.	+	.	.	.
Hedeoma drummondii	HEDR	8	.	.	.	.	.	.	.	+	.	.	.
Hedeoma hyssopifolium	HEHY	59	.	.	.	.	+	.	+	+	+	+	.
Hedeoma oblongifolium	HEOB	31	.	.	.	.	+	.	+	+	.	+	.
Hedyotis acerosa	HEAC	1	.	.	.	.	.	.	.	+	.	.	.
Hedyotis pygmaea	HEPY	77	.	.	.	.	+	.	+	+	+	+	.
(*Houstonia wrightii*)													
Helianthus annuus	HEAN	1	.	.	.	.	.	.	.	+	.	.	.
Heliopsis helianthoides	HEHE	1	.	.	.	.	.	.	.	+	.	.	.
(*H. scabra*)													
Helianthella spp.	HELIA1	4	.	.	+	.	+	.	.	.	.	.	.
Helianthella parryi	HEPA	59	+	+	+	+	+	+	+	+	.	+	.
Helianthus spp.	HELIA2	3	.	.	.	.	+	.	.	+	.	.	.
Helianthella quinquenervis	HEQU	20	.	+	+	+	+	.	.	+	.	.	.
Heracleum sphondylium	HESP	33	.	+	+	+	+	.	.	.	.	.	.
(*H. lanatum*)													
Heterotheca fulcrata	HEFU	201	+	.	.	+	+	.	+	+	.	+	+
(*Chrysopsis villosa* var. *fulcrata*)													
Heterotheca grandiflora	HEGR	2	.	.	.	.	.	.	.	+	.	.	.
Heuchera spp.	HEUCHE	48	+	+	.	+	+	.	+	+	.	.	.
Heuchera eastwoodiae	HEEA	2	.	.	.	.	+	.	+	.	.	.	.
Heuchera novomexicana	HENO	2	.	.	.	.	.	.	+	.	.	.	.
Heuchera rubescens	HERU	2	.	.	.	.	.	.	+	+	.	.	.
Heuchera parvifolia	HEUPA	37	+	+	+	+	+	.	+	+	.	.	.
Heuchera versicolor	HEVE	4	.	.	.	.	.	.	+	.	.	.	.
Hieracium spp.	HIERAC	23	.	+	+	+	+	.	.	+	.	.	.
Hieracium carneum	HICA	7	.	.	.	.	.	.	+	+	.	+	.
Hieracium fendleri	HIFE	394	.	+	+	+	+	.	+	+	+	+	.
Hieracium geyeri	HIGE	1	.	.	.	.	.	.	.	+	.	.	.
Hieracium gracile	HIGR	9	.	+	+	.	.	.	.	.	.	.	.
Hieracium rusbyi	HIRU	3	.	.	.	+	.	.	.	.	.	.	.
Humulus lupulus	HULU	1	.	.	.	+	.	.	.	.	.	.	.
Hydrophyllum fendleri	HYFE	17	+	+	+	+	+	.	.	+	.	.	+
(*H. occidental*)													

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 0 0 0 0 0 0 0 0 0 1 1 / 1 2 3 4 5 6 7 8 9 0 1
---------------- FORBS ----------------	FORBS		
Hymenopappus filifolius	HYFI	27	. . . . + . . + . + .
(H. lugens; H. parvulus; H. pauciflora)			
Hymenopappus mexicanus	HYME	55	. . . . . . + + . . +
Hymenopappus radiatus	HYRA	23	+ + . + + . + + . . .
Hymenothrix wrightii	HYWR	2	. . . . + . + .
Hymenoxys spp.	HYMENX	18	. . + + + . + ...
Hymenoxys bigelovii	HYBI	35	. . . . + . . .
Hymenoxys brandegii	HYBR	1	. . . . + . . .
Hymenoxys cooperi	HYCO	13	. . . . + . . .
Hymenoxys grandiflora	HYGR	1	+ . . . .
Hymenoxys ivesiana	HYIV	11	. . . . + . . .
Hypericum formosum	HYFO	4	. . . + ... +
Ipomopsis aggregata	IPAG	234	+ . + + + . + + . + +
(Gilia aggregata)			
Ipomoea spp.	IPOMOE	13	. . . . + . + + . + +
Ipomoea costellata	IPCO	9	. . . . + . + .
Ipomoea coccinea	IPCOC	1	. . . . + . . .
Ipomoea hederacea	IPHE	1	. . . . + . . .
Iris missouriensis	IRMI	83	. + + + + . + + . . .
Kochia spp.	KOCHIA	1	. . . . + . . .
Eurotia lanata	KRLA	5	. . . . + . . .
(Krascheninnikova lanata)			
Kuhnia rosmarinifolia	KURO	26	. . . . . . + + . + .
(K. chlorolepis)			
Lactuca spp.	LACTUC	2	. . . . + . . .
Lactuca graminifolia	LACGR	4	. . . . + +
Lactuca serriola	LASE	4	. . . . + . . .
(L. scariola)			
Lappula spp.	LAPPUL	1	+ . . . .
Lappula redowskii	LARE	11	. . . . . . + + . . .
Lathyrus spp.	LATHYR	40	. . . + + . + + . . .
Lathyrus arizonicus	LAAR	569	+ + + + + . + + . . +
Lathyrus ariz. x gramini.	LAARGR	1	. . . . + ...
Lathyrus eucosmus	LAEU	3	. . . + . . . + . . .
Lathyrus graminifolius	LAGR	117	. . . + + . + + . . +
Lathyrus leucanthus	LALE	16	. . + . + . + + . . .
Leonurus cardiaca	LECA	1	. . . + ...
Lepidium spp.	LEPEDI	2	. . . . + . . .
Lepidium densiflorum	LEDE	10	. . . . + . . +
Lepidium medium	LEME	3	. . . . + . . .
(L. virginicum)			
Lepidium spp.	LEPIDI	4	+ . . . . . . + . . .
Leptodactylon pungens	LEPU	1	. . . . + . . .
Lesquerella spp.	LESQUE	1	. . . . . . + ...
Lesquerella alpina	LEAL	1	. . . . . . + ...
(L. subumbellata)			
Lesquerella fendleri	LEFE	22	+ . . . + . + + . . .
Lesquerella gordoni	LEGO	1	. . . . + . . .
Lesquerella intermedia	LEIN	3	. . . . + . . .
Lesquerella montana	LESMO	6	. . . . + . . .
Leucelene arenosus	LEAR	4	. . . . + . . .
Leucelene ericoides	LEER	12	. . . . + . + .
Leucanthemum vulgare	LEVU	1	. . . + ...
(Chrysanthemum leucanthemum)			
Liatrus punctata	LIPU	19	. . . . + . . .

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
------------------ **FORBS** ------------------	**FORBS**												
Ligularia amplectens	LIAM	39	.	+	+	.	.	.	.	.	.	.	.
(*Senecio amplectens*)													
Ligularia bigelovii	LIBI	52	.	+	+	+	+	.	+	.	.	.	.
(*Senecio bigelovii*)													
Ligusticum porteri	LIPO	185	.	+	+	+	+	.	+	.	.	.	+
Ligularia pudica	LIPUD	2	+	+	.	.	.	.	.	.	.	.	.
(*Senecio pudicus*)													
Linathus nuttallii	LINU	17	.	.	.	+	+	.	.	+	.	.	.
(*Linanthastrum nuttallii*)													
Linum spp.	LINUM	19	.	.	.	.	+	.	+	+	.	.	.
Linum aristatum	LIAR	11	.	.	.	.	+	.	.	+	.	.	.
Linum lewisii	LILE	22	.	.	.	.	+	.	+	+	.	.	.
Linum neomexicanum	LINE	27	.	.	.	.	.	.	+	+	.	+	.
Listera cordata	LICO	21	.	+	+	.	.	.	.	.	.	.	.
Lithosperum spp.	LITHOS	1	.	.	.	.	.	.	+	.	.	.	.
Lithospermum cobrense	LICOB	6	.	.	.	.	.	.	.	+	.	.	.
Lithosperum incisum	LIIN	1	.	.	.	.	.	.	.	+	.	.	.
Lithospermum multiflorum	LIMU	447	+	+	+	+	+	.	+	+	+	.	+
Lobelia anatina	LOAN	2	.	.	.	.	.	.	.	+	.	.	.
Lotus spp.	LOTUS	27	.	.	+	+	+	.	.	+	.	.	.
Lotus oroboides	LOOR	1	.	.	.	.	.	.	.	.	.	+	.
Lotus utahensis	LOUTA	11	.	.	.	.	.	.	+	+	.	.	.
Lotus wrightii	LOWR	402	.	.	.	.	+	.	+	+	.	+	.
Lotus wrightii x rigidus	LOWRRI	2	.	.	.	.	.	.	.	+	.	.	.
(*L. nummularis*)													
Lupinus spp.	LUPINU	56	.	+	+	+	+	.	+	+	.	.	.
Lupinus argenteus	LUAR	69	.	.	.	+	+	.	+	+	.	.	.
Lupinus blumeri	LUBL	6	.	.	.	.	.	.	.	+	+	+	.
Lupinus hillii	LUHI	39	.	.	.	.	.	.	+	+	.	.	.
Lupinus kingii	LUKI	33	.	.	.	.	+	.	.	+	.	.	.
Lupinus neomexicanus	LUNE	6	.	.	.	.	+	.	+	+	.	.	+
Lupinus palmeri	LUPAL	3	.	.	.	.	.	.	.	+	.	.	.
Lupinus pulsillus	LUPU	4	.	.	.	.	.	.	.	+	.	.	.
Lupinus sierra-blancae	LUSB	2	.	.	.	.	+	.	.	.	.	.	.
Machaeranthera bigelovii	ASBI	5	.	.	.	.	+	.	+	+	.	.	.
(*Aster pattersonii; A. bigelovii*)													
Machaeranthera pinnatifida	MAPI	9	.	.	.	+	.	.	+	+	.	.	.
(*Haplopappus spinulosus*)													
Macromeria viridiflora	MAVI	12	.	.	+	.	+	.	+	+	.	.	.
Malaxis ehrenbergii	MAEH	7	.	.	.	.	+	.	+	.	.	.	.
Malaxis soulei	MASO	55	.	.	+	.	+	.	+	+	.	+	.
Mammillaria spp.	MAMMIL	24	.	.	.	.	.	.	.	+	.	.	.
(*Coryphantha* spp. [in part])													
Mammilaria arizonica	MAAR	1	.	.	.	.	.	.	.	+	.	.	.
Mariscus schweinitzii	MASC	2	.	.	.	.	.	.	.	+	.	.	.
(*Cyperus schweinitzii*)													
Medicago lupulina	MEDLU	1	.	.	.	+	.	.	.	.	.	.	.
Melampodium cinereum	MECI	4	.	.	+	.	.	.	.	+	.	.	.
Melilotus alba	MEAL	3	.	.	.	.	.	.	.	+	.	.	.
Melilotus officinalis	MEOF	6	.	.	.	+	+	.	.	+	.	.	.
Mentha arvensis	MEAR	8	.	.	+	+	+	.	.	.	.	.	.
Mentzelia pumila	MEPU	3	.	.	.	.	.	.	.	+	.	.	.
Mertensia spp.	MERTEN	9	.	+	+	.	+	.	.	+	.	.	.
Mertensia ciliata	MECIL	96	+	+	+	+	+	.	.	.	.	.	.
Mertensia franciscana	MEFR	81	.	+	+	+	+	.	+	+	.	.	+

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----------------- **FORBS** -----------------	**FORBS**												
Mertensia lanceolata	MELA	36	+	+	+	+	+	.	+	+	.	.	.
Mertensia viridus	MEVI	3	+	+	.	.	.	.	.	.	.	.	.
Mimulus spp.	MIMULU	1	.	.	.	.	.	.	.	+	.	.	.
Mimulus guttatus	MIGU	7	.	+	+	+	.	.	.	.	.	.	+
Mirabilis multiflora	MIMU	2	.	.	.	.	+	.	.	.	.	.	.
Mirabilis oxybaphoides	MIOX	7	.	.	.	.	+	.	+	+	.	.	.
Mirabilia spp.	MIRABI	1	.	.	.	.	.	.	.	+	.	.	.
Mitella pentandra	MIPE	24	.	+	+	.	.	.	.	.	.	.	.
Moehringia macrophylla	MOMA	7	.	.	+	.	+	.	.	+	.	.	.
(*Arenaria macrophylla*)													
Monarda spp.	MONARD	5	.	.	.	.	.	.	.	+	.	+	.
Monarda austromontana	MOAU	1	.	.	.	.	.	.	.	+	.	.	.
Monarda fistulosa var. *menthaefolia*	MOFI	24	.	.	.	+	+	.	.	+	.	.	+
Monarda pectinata	MOPE	5	.	.	.	.	.	.	.	+	.	+	.
Monardella odoratissima	MOOD	1	.	.	.	.	.	.	+	.	.	.	.
Moneses uniflora	MOUN	85	.	+	+	+	.	.	.	.	.	.	.
(*Pyrola uniflora*)													
Monotropa latisquama	MOLA	29	.	+	+	+	+	.	+	+	.	.	.
(*M. hypotitys*)													
Myosotis scorpiodes	MYSC	6	.	.	.	.	+	.	+	+	.	.	.
Oenothera spp.	OENOTH	12	.	.	.	+	+	.	+	+	.	.	+
Oenothera caespitosa	OECA	10	.	.	.	+	.	.	+	+	.	.	.
Oenothera coronopifolia	OECO	4	.	.	.	.	.	.	.	+	.	.	.
Oenothera hookeri	OEHO	5	.	.	+	.	.	.	+	+	.	.	+
Oenothera pubescens	OEPU	10	.	.	.	.	.	.	+	+	.	.	+
(*O. laciniata*)													
Oenothera rosea	OERO	1	.	.	.	.	.	.	.	+	.	.	.
Oenothera villosa	OEVI	1	.	.	.	.	.	.	.	+	.	.	.
(*O. strigosa*)													
Oreoxis alpina	ORAL	8	.	+	.	.	+	.	.	.	.	.	.
Oreoxis bakeri	ORBA	3	.	+	+	.	.	.	.	.	.	.	.
Oreochrysum parryi	ORPA	459	+	+	+	+	+	+	+	+	.	.	.
(*Haplopappus parryi; Solidago parryi*)													
Orobanche cooperi	ORCO	4	.	.	.	+	+	.	.	+	.	.	.
(*O. ludoviciana* var. *cooperi*)													
Orobanche fasciculata	ORFA	1	.	.	.	.	.	.	.	+	.	.	.
Orobanche multiflora	ORMU	16	.	.	.	.	+	.	+	+	.	.	.
Orobanche sp.	OROBAN	1	.	.	.	.	.	.	.	+	.	.	.
Orthocarpus luteus	ORLU	3	.	.	.	+	.	.	.	+	.	.	.
Orthocarpus purpureo-albus	ORPU	4	.	.	.	.	.	.	.	+	.	.	.
Osmorhiza chilensis	OSCH	9	.	.	.	+	+	.	+	+	.	.	.
Osmorhiza depauperata	OSDE	302	+	+	+	+	+	.	+	+	.	.	+
(*O. obtusa*)													
Oxalis spp.	OXALIS	14	.	.	+	+	+	.	.	+	.	.	.
Oxalis decaphylla	OXDE	5	.	.	.	.	.	.	+	+	.	+	.
(*O. grayi*)													
Oxalis metcalfei	OXME	98	.	+	+	+	+	.	+	+	.	.	+
(*O. alpina*)													
Oxalis violacea	OXVI	5	.	.	.	+	+	.	.	+	.	.	.
Oxybaphus spp.	OXYBAP	5	.	.	.	.	.	.	+	+	.	+	.
Oxybaphus comatus	OXCO	8	.	.	.	.	+	.	+	+	.	.	.
(*Mirabilis comatus*)													
Oxybaphus linearis	OXLI	28	.	.	.	.	+	.	+	+	.	.	.
(*Mirabilis linearis*)													
Oxybaphus pumilis	OXPU	2	.	.	.	.	.	.	.	+	.	.	.
(*Mirabilis pulmilia*)													

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---------------- **FORBS** ----------------	**FORBS**												
Oxypolis fendleri	OXFE	31	.	+	+	+	.	.	.	.	.	.	+
Oxytropis spp.	OXYTRO	4	.	.	.	.	+	.	.	+	.	.	.
Oxytropis lambertii	OXLA	68	.	.	.	+	+	.	+	+	+	+	.
Oxytropis sericea	OXSE	1	.	.	.	.	.	.	.	+	.	.	.
Parnassia fimbriata	PAFI	2	.	.	+	.	.	.	.	.	.	.	.
Parthenocissus spp.	PARTHE	3	.	.	.	.	+	.	.	+	.	.	.
Pedicularis spp.	PEDICU	19	.	.	+	.	+	.	+	+	.	.	.
Pedicularis angustifolia (*P. angustissima*)	PEAN	11	.	.	+	+	+	.	.	.	.	.	.
Pedicularis canadensis	PECAN	2	.	.	+	.	+	.	.	.	.	.	.
Pedicularis centranthera	PECE	97	.	.	.	.	+	.	+	+	.	.	.
Pedicularis bracteosa	PEDBR	11	.	+	+	.	.	.	.	.	.	.	.
Pedicularis grayi	PEGR	65	.	+	+	+	+	.	+	.	.	.	.
Pedicularis groenlandica	PEGRO	1	.	+	.	.	.	.	.	.	.	.	.
Pedicularis racemosa	PERA	102	.	+	+	+	+	.	.	.	.	.	.
Pelleae spp.	PELLEA	3	.	.	.	.	.	.	+	+	.	.	.
Pellaea atropurpurea	PEAT	10	.	.	.	.	+	.	+	+	.	+	.
Pellaea wrightiana	PEWR	3	.	.	.	.	.	.	.	+	.	+	.
Penstemon spp.	PENSTE	257	.	+	+	+	+	.	+	+	.	+	.
Penstemon barbatus	PEBA	328	+	+	+	+	+	+	+	+	+	+	+
Penstemom bridgesii	PEBR	20	.	+	+	.	+	.	+	+	.	.	.
Penstemom eatoni	PEEA	1	.	.	.	.	.	.	+	.	.	.	.
Penstemon griffinii (*P. oliganthus*)	PEGRI	34	.	+	.	.	+	.	+	+	.	.	.
Penstemon linarioides	PELI	104	.	.	.	.	+	.	+	+	.	.	.
Penstemon pinifolius	PEPI	12	.	.	.	.	+	.	+	+	.	.	.
Penstemom pseudospectabilis	PEPS	3	.	.	.	.	.	.	.	+	.	+	.
Penstemom strictus	PEST	1	.	.	.	+	.	.	.	.	.	.	.
Penstemon virgatus	PEVI	115	+	.	+	+	+	.	+	+	.	+	.
Penstemon virgatus var. *ariz.* (*P. deaveri*)	PEVIAR	4	.	.	+	.	+	.	+	.	.	.	.
Penstemom virens	PENVI	3	.	.	.	.	.	+	+	.	.	.	.
Penstemon whippleanus	PEWH	30	+	+	+	+	+	.	+	+	.	.	+
Perezia spp.	PEREZI	1	.	.	.	.	.	.	.	.	.	+	.
Pericome caudata	PECAU	6	.	.	.	+	+	.	+	.	.	.	.
Perityle ciliata	PECI	3	.	.	.	.	.	.	+	+	.	.	.
Petalostemom spp.	PETALO	2	.	.	.	.	.	.	.	+	.	.	.
Petalostemon pupureum (*Dalea purpurea*)	DAPU	8	.	.	.	.	.	.	.	+	.	.	.
Petasites sagittata	PESA	4	.	.	+	+	.	.	.	.	.	.	.
Petrophytun caespitosum	PETCA	1	.	.	.	.	.	.	+	.	.	.	.
Phacelia spp.	PHACEL	26	+	.	+	+	+	.	+	+	.	.	+
Phacelia heterophylla	PHHE	18	.	+	.	+	+	.	+	+	.	.	.
Phacelia ivesiana	PHIV	2	.	.	.	.	.	.	.	+	.	.	.
Phacelia magellanica	PHMA	7	.	+	.	+	+	.	.	+	.	.	.
Phacelia neomexicana	PHNE	1	.	.	.	.	.	.	+	.	.	.	.
Phaseolus spp.	PHASEO	13	.	.	.	.	.	.	+	+	+	+	.
Phaseolus acutifolius	PHAC	2	.	.	.	.	+	.	.	.	.	+	.
Phaseolus angustissimus	PHAN	2	.	.	.	.	.	.	.	+	.	+	.
Phaseolus grayanus	PHGR	1	.	.	.	.	.	.	.	+	.	.	.
Phaseolus metcalfei	PHME	9	.	.	.	.	.	.	+	+	.	.	.
Phaseolus parvulus	PHPA	7	.	.	.	.	+	.	+	+	.	.	.
Phaseolus wrightii	PHWR	11	.	.	.	.	.	.	.	+	.	+	.
Phlox spp.	PHLOX	63	.	.	.	.	+	.	+	+	.	.	.
Phlox amabilis	PHAM	2	.	.	.	.	.	.	.	+	.	.	.

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 01 02 03 04 05 06 07 08 09 10 11
------------------ **FORBS** ------------------	**FORBS**		
Phlox condensata	PHCON	3	+ + ...
(*P. caespitosa*)			
Phlox nana	PHNA	6	. . . . + . . .
Phlox woodhousei	PHWO	5	. . . . + . . .
(*P. speciosa* ssp. *woodhooseii*)			
Physalis virginiana var. *sonorae*	PHVI	2	. . . . + . . .
(*P. longiflora*)			
Plantago spp.	PLANTA	1	. . . . + . . .
Plantago major	PLMA	2	. . . + ... +
Plantago patagonica	PLPA	12	. . . . + . . .
(*P. purshii*)			
Plummera floribunda	PLFL	7	. . . . + + + .
Polemonium spp.	POLEMO	12	. + + + + ...
Polemonium foliosissimum	POFO	17	. . + + + . + + . . .
Polemonium pulcherrimum	POPU	81	+ + + . + ...
Polemonium viscosum	POVI	8	+ . + . + . + + . . .
Polygala spp.	POLYGA	1	. . . . + . . .
Polygala alba	POAL	8	. . . . + . . .
Polygala obscura	POOB	1	. . . . + .
Polygala longa	POLO	45	. . . . + . . + . + .
Polygonum spp.	POLYGO	1	. . . . + . . .
Polygonum sawatchensis	POSA	191	. . . + + . + + . + .
Potentilla spp.	POTENT	50	+ + + + + . + + . . .
Potentilla concinna	POCON	3	. + ... + . . .
Potentilla crinita	POCR	71	. . . + . . + + . . .
Potentilla diversifolia	PODI	7	. + + ...
Potentilla gracilis v pulcher	POGR	86	+ + + + + . + + . . .
(*P. pulcherrima*)			
Potentilla hippiana	POHI	124	+ + + + + . + + . . .
Potentilla norvegica	PONO	2	. . . + . . + ...
Potentilla pennsylvanica	POPE	9	+ . . + + . . + . . .
Potentilla subviscosa	POSU	15	. + + ... + . . .
Potentilla anserina	POTAN	1	. . . + ...
Potentilla thurberi	POTH	20	. + . + + . + ...
Primula ellisiae	PREL	8	. . . . + . + ...
Primula parryi	PRPA	8	. + + ...
Prunella vulgaris	PRVU	23	. + + + + . . + . . +
Pseudostellaria jamesiana	PSJA	66	+ + + + + . + + . . .
(*Stellaria jamesiana*)			
Pseudocymopteris montanus	PSMO	842	+ + + + + . + + + + +
Psoralea tenuiflora	PSTE	36	. . . . + . . .
Pterospora andromedea	PTAND	54	. + + + . + + + . . .
Pteridium aquilinum	PTAQ	216	. + + + + . + + . . +
Pulsatilla patens	PUPA	35	+ . . + + . + + . . .
Pyrola spp.	PYROLA	2	. . + . . . + ...
Pyrola asarifolia	PYAS	30	. + + + + ...
Pyrola chlorantha	PYCH	155	. + + + + . + + . . +
(*P. virens*)			
Pyrola minor	PYMI	4	. + + ...
Pyrola picta	PYPI	40	. + + + + . + + . . +
Ramischia secunda	ORSE	344	+ + + + + . + ...
(*Orthilia secunda*; *Pyrola secunda*)			
Ranunculus spp.	RANUNC	7	. + + + . . + . . . +
Ranunculus aquatilis	RAAQ	1	. . . + ...
(*Batrachium trichophyllus*)			

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----------------- **FORBS** -----------------	**FORBS**												
Ranunculus alismaefolius	RAAL	2	.	.	+	.	.	.	.	.	.	.	.
Ranunculus cardiophyllus	RACA	1	.	.	.	.	+	.	.	.	.	.	.
Ranunculus eschscholtzii	RAES	7	.	+	+	.	.	.	.	.	.	.	.
Ranunculus hydrocharoides	RAHY	1	.	.	.	.	.	.	.	.	.	.	+
Ranunculus inamoenus	RAIN	9	.	.	+	+	+	.	+	+	.	.	.
Ranunculus macounnii	RAMA	2	.	.	.	+	.	.	.	.	.	.	.
Ranunculus uncinatus	RAUN	2	.	.	+	.	.	.	.	.	.	.	.
Ratibida columnaris	RACO	3	.	.	.	.	.	.	.	+	.	.	.
Rhodiola integrifolia	RHIN	14	+	+	+	.	.	.	+	.	.	.	.
(*Sedum rosea*)													
Rudbeckia hirta	RUHI	6	.	.	.	+	.	.	.	+	.	.	.
Rudbeckia laciniata	RULA	21	.	.	+	+	+	.	.	+	.	.	+
Acetosella vulgaris	ACVU	4	.	.	.	+	.	.	.	.	.	.	+
(*Rumex acetocella*)													
Rumex crispus	RUCR	2	.	.	.	+	.	.	.	.	.	.	+
Rumex occidentalis	RUOC	3	.	.	.	+	.	.	.	.	.	.	+
Salsola kali	SAKA	2	.	.	.	.	.	.	.	+	.	.	.
Salvia arizonica	SAAR	4	.	.	.	.	.	.	+	+	.	.	.
Salvia davidsonii	SADA	1	.	.	.	.	.	.	.	+	.	.	.
Salvia lemmoni	SALE	2	.	.	.	.	.	.	+	.	.	+	.
Saxifraga bronchialis	SABR	51	+	+	+	+	+	+	+	+	.	.	.
Saxifraga eriophora	SAER	1	.	.	.	.	.	.	.	+	.	.	.
Saxifraga odontoloma	SAOD	9	.	+	+	.	.	.	.	.	.	.	.
Saxifraga rhomboidea	SARH	9	+	+	.	.	+	.	.	+	.	.	.
Saxifraga spp.	SAXIFR	11	.	+	+	.	+	.	+	.	.	.	.
Scrophularia parviflora	SCPA	18	.	.	+	.	+	.	+	+	.	+	+
Scutellaria spp.	SCUTEL	1	.	.	.	+	.	.	.	.	.	.	.
Sedum spp.	SEDUM	30	.	+	+	+	+	.	+	+	.	.	.
Sedum cockerellii	SECO	2	.	.	.	.	.	.	.	+	.	.	.
Sedum griffthsii	SEDGR	1	.	.	.	.	.	.	.	+	.	.	.
Sedum lanceolatum	SELA	27	+	+	+	.	+	+	+	+	.	.	.
(*S. stenopetalum*)													
Senecio spp.	SENECI	19	.	.	+	+	+	.	+	+	.	.	.
Senecio actinella	SEAC	43	.	.	.	.	+	.	+	+	.	.	.
Senecio arizonica	SEAR	2	.	.	.	.	.	.	+	.	.	.	.
Senecio atratus	SEAT	10	+	+	+	.	.	.	.	.	.	.	.
Senecio cardamine	SECA	43	.	+	+	+	+	.	+	.	.	.	.
Senecio crocatus	SECR	1	.	.	+	.	.	.	.	.	.	.	.
Senecio cynthioides	SECY1	25	.	.	.	+	+	.	+	+	.	.	.
Senecio dimorphophyllus	SEDI	1	.	.	+	.	.	.	.	.	.	.	.
Senecio douglasii	SEDO	1	.	.	.	.	.	.	.	+	.	.	.
Senecio eremophilus	SEER	53	.	.	+	+	+	.	+	+	.	+	.
Senecio fendleri	SEFE	110	+	+	+	+	+	+	+	+	.	.	.
Senecio hartianus	SEHA	16	.	.	.	+	+	.	+	+	.	.	.
Senecio integerrimus	SEIN	2	.	.	.	.	.	.	.	+	.	.	.
Senecio lemmoni	SELE	2	.	.	.	.	+	.	.	.	.	.	.
Senecio macdougalii	SEMA	16	.	.	+	+	+	.	+	.	.	.	.
(*S. eremophillus* var. *macdougalii*)													
Senecio multilobatus	SEMU	71	.	.	.	.	.	.	.	+	.	.	.
Senecio neomexicanus	SENE	563	+	+	+	+	+	.	+	+	+	+	+
Senecio neomexicanus var. *mut.*	SENEMU	19	.	.	+	+	+	.	+	+	.	.	.
(*S. mutabilis*)													
Senecio quaerens	SEQU	8	.	.	.	+	+	.	.	.	.	.	+
Senecio sanguisorboides	SESA	27	.	+	+	+	+	.	.	.	.	.	.
Senecio sacramentanus	SESAC	14	.	.	.	+	+	.	+	.	.	.	.

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
---------------- FORBS ----------------	FORBS												
Senecio serra	SESE	10	.	.	+	.	.	.	.	.	.	.	.
Senecio spartioides	SESP	3	.	.	.	.	.	.	+	+	.	.	.
Senecio streptanthifolius (*S. cymbalarioides*)	SEST	28	.	+	+	+	+	.	.	.	.	.	.
Senecio triangularis	SETR	16	.	+	+	.	.	.	.	.	.	.	.
Senecio wootoni	SEWO	328	.	+	+	+	+	.	+	+	.	+	+
Sibbaldia procumberns	SIPR	14	.	+	+	.	.	.	.	.	.	.	.
Sidalcea neomexicana	SINE	8	.	.	.	+	+	.	.	+	.	.	.
Silene spp.	SILENE	14	.	+	.	+	+	.	+	.	.	.	.
Silene acaulis	SIAC	3	+	.	.	+	.	.	.	.	.	.	.
Silene antirrhina	SIAN	1	.	.	.	.	.	.	.	+	.	.	.
Silene laciniata	SILA	71	.	.	.	+	+	.	+	+	+	.	.
Silene menziesii	SIME	21	.	+	+	+	+	.	+	+	.	.	.
Silene scouleri	SISC	87	+	+	+	+	+	.	+	+	.	.	.
Sisymbrium altissimum	SIAL	10	.	.	.	.	.	.	+	+	.	.	+
Sisyrinchium angustifolium (*S. demissum*)	SIANG	4	.	.	.	.	.	.	.	+	.	.	.
Sisyrinchium arizonicum	SIAR	1	.	.	.	.	.	.	.	+	.	.	.
Sisymbrium spp.	SISYMB	33	.	.	.	.	+	.	+	+	.	.	.
Sisymbrium irio	SIIR	7	.	.	.	.	+	.	.	+	.	.	.
Smilacina racemosa	SMRA	299	.	+	+	+	+	.	+	+	.	.	+
Smilacina stellata	SMST	318	+	+	+	+	+	.	+	+	.	.	+
Solanum spp.	SOLAN	1	.	.	.	.	+	.	.	.	.	.	.
Solidago spp.	SOLIDA	167	+	+	+	+	+	+	+	+	.	+	+
Solidago altissima	SOAL	5	.	.	.	.	.	.	.	+	.	.	.
Solidago canadensis	SOCA	4	.	.	.	+	+	.	.	+	.	.	.
Solidago missouriensis	SOMI	17	.	.	.	+	+	+	.	+	.	.	.
Solidago miss. var. *extraria*	SOMIEX	1	.	.	.	.	.	.	.	+	.	.	.
Solidago sparsiflora	SOSP	267	.	.	.	+	+	.	+	+	+	+	.
Solidago spathulata var. *nana*	SOSPNA	4	.	+	.	.	.	.	.	+	.	.	.
Solidago spathulata var. *neomexicana* (*S. decumbens*)	SOSPNE	46	+	.	+	+	+	+	+	+	.	.	.
Solidago wrightii	SOWR	44	.	.	.	.	+	.	+	+	+	+	.
Sonchus asper	SOAS	1	.	.	.	.	.	.	.	.	.	.	+
Sphaeralcea fendleri	SPFE	5	.	.	.	.	.	.	.	+	.	.	.
Sphaeralcea grossulariaefolia	SPGR	1	.	.	.	.	.	.	.	+	.	.	.
Sphaeralcea coccinea	SPHAER	25	.	.	.	.	.	.	.	+	.	.	.
Spiranthes parasitica	SPPA	2	.	.	.	+	.	.	.	.	.	.	.
Stachys coccinea	STCOC	7	.	.	.	+	+	.	.	+	.	.	.
Stachys palustris	STPA	3	.	.	.	+	+	.	.	.	.	.	.
Stellaria spp.	STELLA	26	+	+	+	+	+	.	+	+	.	.	.
Stellaria longipes (*S. laeta*)	STLA	17	.	+	+	+	+	.	.	+	.	.	.
Stellaria longifolia	STLO1	26	.	.	+	+	+	.	+	.	.	.	.
Stellaria umbellata	STUM	14	.	+	+	.	+	.	+	.	.	.	.
Stephanomeria exigua	STEX	2	.	.	.	.	.	.	.	+	.	.	.
Stevia spp.	STEVIA	13	.	.	.	.	+	.	+	+	.	.	.
Stevia plummerae	STPL	6	.	.	.	.	.	.	+	+	.	+	.
Stevia serrata	STSE	10	.	.	.	.	.	.	+	+	+	+	.
Streptopus amplexifolius	STAM	46	.	+	+	.	+	.	.	.	.	.	.
Streptanthus spp.	STREPT	2	.	+	.	.	.	.	.	+	.	.	.
Swertia perennis	SWPE	2	.	.	+	.	.	.	.	.	.	.	.
Talinum spp.	TALINU	1	.	.	.	.	.	.	.	+	.	.	.
Taraxacum spp.	TARAXA	44	.	+	+	+	+	.	+	+	.	.	+
Taraxacum laevigatum	TALA	3	.	.	.	+	.	.	+	.	.	.	.

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO. 01	02	03	04	05	06	07	08	09	10	11
----------------- FORBS -----------------	FORBS												
Taraxacum officinale	TAOF	159	+	+	+	+	+	.	+	+	.	+	.
Tetradymia canescens	TECA	4	.	.	.	.	.	.	.	+	.	.	.
Teucrium spp.	TEUCRI	1	.	.	.	.	.	.	.	+	.	.	.
Thalictrum fendleri	THFE	730	+	+	+	+	+	.	+	+	+	+	+
Thelypodiopsis linearifolia (*Sisymbrium linarifolium*)	SILI	92	.	.	.	.	+	.	+	+	+	+	.
Thelypodium spp.	THELYP	1	.	.	.	.	.	.	+	.	.	.	.
Thelypodium longifolium (*Pennelia longifolia*)	THLO	4	.	.	.	.	.	.	.	+	+	.	.
Thelypodium micanthum (*Pennelia micranthum*)	PEMI	7	.	.	.	.	+	.	.	+	+	+	.
Thelypodium wrightii	THWR	2	.	.	.	.	+	.	.	+	.	.	.
Thelesperma filifolium	THFI	2	.	.	.	.	.	.	.	+	.	.	.
Thelesperma megapotamicum	THME	9	.	.	.	.	.	.	.	+	.	.	.
Thermopsis spp.	THERMO	2	+	.	.	.	.	.	.	+	.	.	.
Thermopsis divaricarpa (*T. pinetorum*)	THDI	153	+	+	+	+	+	.	+	+	+	+	.
Thermopsis montana	THMO	8	+	.	.	+	.	+	.	+	.	.	.
Thlaspi spp.	THLASP	29	.	+	+	+	+	.	+	+	.	.	.
Thlaspi arvense	THLAR	3	.	+	.	+	.	.	.	.	.	.	.
Thlaspi fendleri	THLFE	2	.	.	.	.	.	.	+	.	.	.	.
Thlaspi montanum (*T. fendleri*)	THLMO	145	+	+	+	+	+	.	+	+	.	+	+
Townsendia spp.	TOWNSE	3	.	.	.	.	.	.	.	+	.	.	.
Townsendia eximia	TOEX	19	.	.	.	+	.	.	+	+	.	.	.
Townsendia exscapa	TOEXS	4	.	.	.	.	.	.	.	+	.	+	.
Townsendia formosa	TOFO	32	.	+	+	+	+	.	+	+	.	.	.
Tradescatia pinetorum	TRAPI	20	.	.	.	.	.	.	.	+	+	+	.
Tradescantia occidentalis	TROC	1	.	.	.	.	.	.	.	+	.	.	.
Tragopogon spp.	TRAGOP	43	.	.	.	.	.	.	+	+	.	.	+
Tragopogon dubius	TRADU	24	.	.	.	.	.	.	+	+	.	.	.
Tragopogon pratensis	TRAPR	2	.	.	.	.	.	.	.	+	.	.	.
Tragia stylaris (*T. ramosa*)	TRST	41	.	.	.	.	+	.	+	+	+	+	.
Trautvetteria carolinensis (*T. grandis*)	TRCA	12	.	+	+	+	.	.	.	.	.	.	.
Trifolium spp.	TRIFOL	28	.	+	+	+	+	.	+	+	.	.	.
Trifolium brandegei	TRBR	4	.	+	.	.	.	.	.	.	.	.	.
Trifolium dasyphyllum	TRDA	9	+	+	+	+	.	.	.	.	.	.	.
Trifolium dubium	TRDU	19	.	.	.	.	+	.	+	+	.	.	.
Trifolium neurophyllum (*T. longipes*)	TRNE	6	.	.	.	.	.	.	.	+	.	.	.
Trifolium parryi	TRPA	1	.	.	.	.	.	.	.	+	.	.	.
Trifloium rusbyi	TRRU	2	.	.	.	.	.	.	.	+	.	.	.
Trifolium subcaulescens	TRSU	1	.	.	.	.	.	.	.	+	.	.	.
Trifolium wormskjoldii	TRWO	1	.	.	.	+	.	.	.	.	.	.	.
Trollis laxis	TRLA	11	.	+	+	.	.	.	.	.	.	.	.
Urtica spp.	URTICA	11	.	.	.	+	+	.	.	.	.	.	+
Valeriana spp.	VALERI	24	.	.	+	+	+	.	+	.	.	.	.
Valeriana arizonica	VAAR	3	.	.	.	.	+	.	+	.	.	.	.
Valeriana capitata ssp. *acutiloba*	VACA	89	.	+	+	+	+	.	+	+	.	.	+
Valeriana edulis	VAED	19	+	+	.	+	+	.	+	+	.	.	.
Veratrum californicum	VECA	18	.	+	+	+	.	.	.	+	.	.	+
Verbena spp.	VERBEN	3	.	.	.	.	.	.	+	+	.	.	.
Verbena ambrosiofolia	VEAM	3	.	.	.	+	.	.	.	.	.	.	+

SPECIES NAME	SPECIES CODE	NO OF OBS	SERIES NO.										
			01	02	03	04	05	06	07	08	09	10	11
------------------ FORBS ------------------	FORBS												
Verbena bipinnatifida	VEBI	11	.	.	.	.	.	.	+	+	.	+	.
Verbesina longifolia	VELO	5	.	.	.	.	+	.	+	.	.	.	.
Verbena macdougalii	VEMA	5	.	.	.	.	+	.	+	+	.	.	.
Verbena neomexicana	VENE	1	.	.	.	.	.	.	.	+	.	.	.
Verbascum thapsus	VETH	47	.	.	.	+	+	.	+	+	.	.	+
Verbena wrightii	VEWR	9	.	.	.	.	+	.	.	+	.	.	.
Veronica spp.	VERONI	4	.	.	+	+	.	.	.	.	.	.	.
Veronica peregrina	VEPE	1	.	.	.	.	.	.	.	+	.	.	.
Veronica serphyllifolia	VESE	2	.	.	+	+	.	.	.	.	.	.	.
Veronica wormskjoldii	VEWO	14	.	+	+	.	.	.	.	.	.	.	.
Vicia spp.	VICIA	19	.	.	.	+	+	.	+	+	.	.	.
Vicia americana	VIAM	505	+	+	+	+	+	.	+	+	+	.	+
Vicia leucophaea	VILE	10	.	.	.	.	+	.	+	+	.	.	.
Vicia ludoviciana var. *texana* (*V. exigua*)	VILU	2	.	.	.	+	.	.	.	.	.	.	.
Vicia pulchella	VIPU	82	.	+	+	.	+	.	+	+	.	.	+
Vicia villosa	VIVI	1	.	.	.	.	.	.	.	+	.	.	.
Viguiera spp.	VIGUIE	64	.	.	.	.	.	.	+	+	.	.	.
Viguiera annua	VIAN	5	.	.	.	.	.	.	.	+	.	.	.
Viguiera cordifolia	VICO	7	.	.	.	.	.	.	.	+	.	.	+
Viguiera dentata	VIDE	2	.	.	.	.	.	.	.	.	.	+	.
Viguiera multiflora (*Heliomeris multifloa*)	VIMU	116	.	.	.	+	+	.	+	+	.	+	.
Viola spp.	VIOLA	7	.	+	+	+	+	.	.	.	.	.	.
Viola adunca	VIAD	37	.	+	+	+	+	.	.	+	.	.	.
Viola canadensis	VICA	397	.	+	+	+	+	.	+	+	.	.	+
Viola nephrophylla	VINE	13	.	+	+	+	+	.	.	.	.	.	+
Woodsia spp.	WOODSI	26	.	.	+	.	+	.	+	+	.	.	.
Woodsia mexicana	WOME	6	.	.	.	.	.	.	+	+	.	.	.
Woodsia oregana	WOOR	2	.	.	.	.	.	.	+	+	.	.	.
Wyethia amplexicaulis	WYAM	4	.	.	.	.	.	.	+	+	.	.	.
Wyethia arizonica	WYAR	6	.	.	.	.	.	.	+	+	.	.	.
Zygadenus spp.	ZYGADE	51	.	+	+	+	+	.	.	.	.	.	.
Zygadenus elegans (*Anticlea elegans*)	ZYEL	117	+	+	+	+	+	.	+	+	.	.	.
Zygadenus virescens	ZYVI	5	.	.	+	.	+	.	.	.	.	.	.

APPENDIX B

Consolidated Series Stand Tables

There are 11 consolidated series stand tables for southwestern habitat types, one for each climax tree series. Below we provide an example of the tables using the *Picea engelmannii* series. To output the set of tables in their complete form, follow the instructions given in "Creating a Stand Table" using the parameter files as given on sloppy disk. The complete set of tables is also archived at the Rocky Mountain Experiment Station library, 240 W. Prospect Road, Fort Collins, CO 80526.

At the beginning of each table is a list of habitat types included for that series and the associated habitat type and phase numbers. The tables are presented with plots going across the page and species observations going down. The first three lines are the habitat type and phase numbers (read vertically), corresponding to the above list of habitat types. Plots are identified by a five-digit code of the Principal Investigator responsible for the plot, the general Geographic Location, and the Plot Number assigned by the principal investigation (also read vertically).

The Principal Investigator codes are:

Code	Principal investigator
A	Alexander, Billy G.
E	Muldavin, Esteban H.
F	Fitzhugh, E. Lee
D	DeVelice, Robert L.
L	Ludwig, John A.
M	Moir, William H.
W	White, Alan S.

The Geographic Location codes are:

Code	Location
C	Cibola National Forest, central New Mexico.
G	Gila National Forest, southwestern New Mexico, Apache National Forest, eastern Arizona.
H	Hualapai Indian Reservation, northwest Arizona.
K	Coronado National Forest, southeastern Arizona.
L	Lincoln National Forest, south-central New Mexico.
M	Mogollon Plateau, including the Coconino, Apache-Sitgreaves, and Kaibab National Forests of northern Arizona.
N	Northern New Mexico and southern Colorado, including the Santa Fe, Carson, San Isabel, San Juan, and Rio Grande National Forests.
P	Prescott National Forest, west-central Arizona.
S	San Carlos Indian Reservation, central Arizona.
T	Tonto National Forest, central Arizona.
W	Fort Apache Indian Reservation (White River), east-central Arizona.

Density (stems per 375 m^2) and percent cover values for species observations have been converted into 1-column scalars as follows:

Density conversion

Table scalar	Data value	
+	=1	stem
1	=2	stems
2	=3–4	stems
3	=5–9	stems
4	=10–20	stems
5	=21–40	stems
6	=41–60	stems
7	=61–80	stems
8	=81–99	stems
9	=100 or more	

Percent cover conversion

Table scalar	Data value	
P	= +0 (present)	
+	= <1	%
1	=1–4	%
2	=5–24.9	%
3	=25–49.9	%
4	=50–74.9	%
5	=75–100	%

TABLE B.1 PICEA ENGELMANNII SERIES

HT NO	PHASE NO	HABITAT TYPE NAME
12	1	PICEA ENGELMANNII/GEUM ROSSII HT
5	1	PICEA ENGELMANNII/MOSS HT
1	1	PICEA ENGELMANNII/VACC. MYRTILLUS/POLE. PULCHERRIMUM HT, PIEN PH
2	2	PICEA ENGELMANNII/VACC. MYRTILLUS/POLE. PULCHERRIMUM HT, ABLA PH
2	1	PICEA ENGELMANNII/VACCINIUM MYRTILLUS HT
5	1	PICEA ENGELMANNII/SENECIO CARDAMINE HT, ABIES LASIOCARPA PH
5	2	PICEA ENGELMANNII/SENECIO CARDAMINE HT, ABIES CONCOLOR PH
6	1	PICEA ENGELMANNII/ACER GLABRUM HT
10	1	PICEA ENGELMANNII/ERIGERON EXIMIUS HT
9	1	PICEA ENGELMANII/CAREX FOENEA HT
7	1	PICEA ENGELMANNII/ELYMUS TRITICOIDES HT
11	1	PICEA ENGELMANNII/HERACLEUM SPONDYLIUM HT
8	1	PICEA ENGELMANNII/SAXIFRAGA BRONCHIALIS HT

TABLE B.1 (CONTINUED) — PICEA ENGELMANNII SERIES

HABITAT TYPE NUMBER:	10000000000000000000000000000000000000000000000000000000000000000000000000000000000000000001111111100
	25555555111111111111112222222222222222222222222222222222222222255555555555555555555566666600000000099
PHASE NUMBER:	1111111111111111111111222222222222222222222222222222222222222222111111111112222222222221111111111111111
PRINCIPLE INVESTIGATOR:	MFAMMMEMLMMMLLMLLMLLLLMMMLLMMLLMLLLLLLLLLLLLLLMLLLLLLLLLLLLLLLMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMDDDEMMMMMMMEMM
GEOGRAPHIC LOCATION:	MCCCCCNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNCCCGGGGGGGGGGGGGGGGGGGGGLLKKKKMGGGGGGGMKK
PLOT NUMBER:	5907771111110211102210011221120122221100011111122220111101117771211101051212105111122400005566002044
	45155302755272699524954421844654452472979666144114695142551255359488807049585907889800000594755886900
	7711951680172782514815565575854940077706530857916924617523618653647988958625953360198689490796012401
- - T R E E S - -	....
ABIES CONCOLOR - YNG REGEN.	....5...1.4224253442165955..4165.456.4..5..
ABIES CONCOLOR - ADV REGEN	...1...2...+.5..1..+...1+5422.1...+.+21.+.....
ABIES CONCOLOR - MATURE	....P5+.2.1+2...21......
ABIES LASIOCARPA - YNG REGEN	26.....2.1.+.1+.5122.1945996679759569549856755595980044555647...75542542.51..+.+.2...........+.....+.
ABIES LASIOCARPA - ADV REGEN	.5....1+..5..+2.521..245262424645545445442445251542525154555...5522515........P.................+...
ABIES LASIOCARPA - MATURE	.5.....2........+2...11425551225.5.142115+5+51222422+2212422...2222115+.....+......................
PICEA ENGELMANNII - YNG REGEN	6.555446284758479.56645.889544446945S5P95+6254444874244+4125845555545+295454444245555557+558573452845
PICEA ENGELMANNII - ADV REGEN	515445555465455456455544446.5445164545455S5+112264445525+441.5552255555.544545551++2551524.5455154545
PICEA ENGELMANNII - MATURE	554P5554555554544444444542224444554444444454545442444555554552555515+1+.22+22515++1145525512525.12+45
PINUS PONDEROSA - ADV REGEN	....+...............P.++..........
PINUS PONDEROSA - MATURE	....1....+.....2....P..+....1+.+..
PICEA PUNGENS - YNG REGEN	....2..12..51+552..+.1...........5544..
PICEA PUNGENS - ADV REGEN	....+..1+..2..2.5.+1...........1.5444..
PICEA PUNGENS - MATURE	....+...2..+.+.5+..................11..
PINUS STROBIFORMIS - YNG REGEN	...25+..545..+.+..52+..25...2.1.1.5.52P+4P+..2..
PINUS STROBIFORMIS - ADV REGEN	...24...+.2....1++5+++.+2...4.......2+P.+.+..+..
PINUS STROBIFORMIS - MATURE	...11...+..........12..+....1.+.....+.P.........
POPULUS ANGUSTIFOLIA-ADV REGEN	....
POPULUS ANGUSTIFOLIA-MATURE	....
POPULUS TREMULOIDES- YNG REGEN	.4..6.........
POPULUS TREMULOIDES- ADV REGEN	...+5+..5.........................5+P4.+.51.....
POPULUS TREMULOIDES - MATURE	...+.+..5555.+2........+.++2+54.++45..P+P1+1+...
PSEUDOTSUGA MENZIESII-YNG REGE	...25...26+545+1555142545254444..4+17442425516..
PSEUDOTSUGA MENZIESII-ADV REGE	...55..1.1.2+.12+55522.2+122.525.1.24.12545+4..
PSEUDOTSUGA MENZIESII - MATURE	...42P...P25122251522+212.12+24521+22555+1+15.1..
- - S H R U B S - -	....
ACER GLABRUM	...2P...+1......P.++...P.+.....+P2+5+....P......
ALNUS TENUIFOLIA	....2..
CHIMAPHILA UMBELLATA	....+.+.........1........+..........
HOLODISCUS DUMOSUS	...P1..+1...+.........P.
JAMESIA AMERICANA	...P..+++.....................1...............
JUNIPERUS COMMUNIS	...11...1.+..............+..................................2.P...............................PP....
LONICERA ARIZONICA	...1+...1.........+.....+P........P..+..........
LONICERA INVOLUCRATA	P......+..........+...P.P.1..1...1+++.2+11+1..+.11.1+.1.++1..
LONICERA UTAHENSIS	...++++..+1P++++++.+.P+P..P+++........+.........
MONESES UNIFLORA	+.............+..++..+1........+P++.....+.+P.+....1.+++.++..
PACHISTIMA MYRSINITES	.................+...1..11.111......1.....1......2..
PHYSOCARPUS MONOGYNUS	...+.+..+P........++.....1.........+..........
POPULUS TREMULOIDES - SHRUBS	....++..+.+1+++..+.+..++.++1+.P+++.++++.+1+...
POTENTILLA FRUTICOSA	..........+...
RIBES SPP.	...P..+...........+......++.......
RIBES MONTIGENUM	2.....+.+.+11+1+P+1++1....+P.+.+++.1+11+.11+.+1++11+11.+.1+......................................+.
RIBES PINETORUM	....+...+.P...........+.P.+.....P............P..

TABLE B.1 (CONTINUED) — PICEA ENGELMANNII SERIES

HABITAT TYPE NUMBER:	10000000000000000000000000000000000000000000000000000000000000000000000000000000000011111111100
	25355351111111111111111222222222222222222222222222222222222222222255555555555555555555556666666600000000099
PHASE NUMBER:	11111111111111111111112222222222222222222222222222222222222222222111111111112222222222221111111111111111
PRINCIPLE INVESTIGATOR:	MFAMMMEMLMMMLLMLLMLLLLMMMLLMMLLMLLLLLLLLLLLLLMLLLLLLLLLLLLLMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMDDDEMMMMMMMEMM
GEOGRAPHIC LOCATION:	MCCCCCMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMCCCGGGGGGGGGGGGGGGGGGGGGLLKKKKMGGGGGGMKK
PLOT NUMBER:	590777111111021110221001122112012222110001111112222011110111777121110105121210511112240000556602044
	45153502755272699524954421844654452472979666144114695142551255359488807049585907889800000594755886900
	77119516801727823148155655758549400777065330857916924617523618653647988958625953360198689490796012401
RIBES WOLFII	.....+.+.+.......+....+.P................1++..+........+.111+.......................1...............
ROBINIA NEOMEXICANA	....++..+.....1.+P.+.....+.......P....+..
ROSA SPP.	....+++.........................
RUBUS IDAEUS VAR. STRIGOSUS	....+.....1..+.....+...............
RUBUS PARVIFLORUS	....++..++1P1+1.1++++...11.....1.++...1..
SALIX SPP.	....+....1........P.
SAMBUCUS RACEMOSA	............................1......................1.....+....+..
SALIX SCOULERIANA	.+.P..P.1.++P....P.................+1.2.+....
SHIDA SERICEA	....+..........................
SYMPHORICARPOS OREOPHILUS	....+.............P...........+......+..P.........
VACCINIUM MYRTILLUS	.+1..1P54443332222222222554444444444433333333322222222222222222521.........P...P............1...........
- - G R A M I N O I D S - -	....
AGROPYRON TRACHYCAULUM	P..
AGROSTIS ALBA	...................................1.............+...
BROMUS CILIATUS	..++P+..+...+1.+.+1+.++.+.+.....+1++++1+..++..+.P+..+++...+++1P+1+1++++1+22+115111+111.+.222521111++
CAREX BELLA	+.............++.P+...+...............+...........+..
CAREX BREVIPES	..................................+..............+...P............
CAREX FOENEA	........1.+.......++..++.+.21++.111++P11P......221..252114
CAREX GEYERI	....2..1..........11....+1.....................................
CAREX ROSSII	..........+..++++++.....+..+.+.....+..............................P++++++.+1+111.1+++............+P....
DESCHAMPSIA CAESPITOSA	.......P.1.............PP......+..............+........+...1..
ELYMUS TRITICOISDES	....
FESTUCA ARIZONICA	....P...........................1....1.2...
FESTUCA OVINA	P.........+.+++++....................+...+...
FESTUCA SORORIA	.......1..P1..+..........+...P.................................P...+++.+..1.+..+.++..1.....+.1+.....+1
FESTUCA THURBERI	.................+..1.....
KOELERIA PYRAMIDATA	....P..........+..+...+.++.++.+......+....1.....
LUZULA PARVIFLORA	+.......+.1.++1+..P+1+.+++.++++.1.+++.....++..2.++11+1.1+.++..
MUHLENBERGIA VIRESCENS	....+.........+......2...
POA ALPINA	..................+...............+...+....................+...
POA FENDLERIANA	........+......++..........................+........................+.P.P+.1++...+.......+....+..+.
POA LEPTOCOMA	............+......+..............+..
POA PRATENSIS	....++................+2...1
POA REFLEXA	.......+.+.+............+..+...+...........1...
SITANION HYSTRIX	....++.+.........+.....+.....
TRISETUM SPICATUM	+.1...+......................................
TRISETUM SPICATUM S. MONTANUM	.....P.........+.....+.....+.....+..+.......+.....+P+......+.....+....+..+..+.+..P1..+.....+++....P..1...+.....
- - F O R B S - -	....
ACHILLEA MILLEFOLIUM	.......++.++...++.+......+.......+......+...........+............+..........++1...........+..+.1.1+.P
ACONASTYLIS ROSSII	.........1...1....+.................+...P.......2.......2...
ACONITUM COLUMBIANUM	.....................................+..................................P.........................
ACTAEA RUBRA SSP. ARGUTA	...................................+.......1............................+.+....++...........P..
ANGELICA GRAVII	.........+.P++P...+++.+...+....+..+.+.........+.+..++..+..
ANTENNARIA ROSULATA	..........+.....++..

TABLE B.1 (CONTINUED) — PICEA ENGELMANNII SERIES

HABITAT TYPE NUMBER:	10000000000000000000000000000000000000000000000000000000000000000000000000000000000011111111100
	25355351111111111111111222222222222222222222222222222222222222222255555555555555555555556666666600000000099
PHASE NUMBER:	11111111111111111111112222222222222222222222222222222222222222222111111111112222222222221111111111111111
PRINCIPLE INVESTIGATOR:	MFAMMMEMLMMMLLMLLMLLLLMMMLLMMLLMLLLLLLLLLLLLLMLLLLLLLLLLLLLMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMDDDEMMMMMMMEMM
GEOGRAPHIC LOCATION:	MCCCCCMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMCCCGGGGGGGGGGGGGGGGGGGGGLLKKKKMGGGGGGMKK
PLOT NUMBER:	590777111111021110221001122112012222110001111112222011110111777121110105121210511112240000556602044
	45153502755272699524954421844654452472979666144114695142551255359488807049585907889800000594755886900
	77119516801727823148155655758549400777065330857916924617523618653647988958625953360198689490796012401
AQUILEGIA CAERULEA	.........+........+.........................+...+....1..+...
AQUILEGIA ELEGANTULA	.+.P........................++.....++...+....1...+...........++...+..11..+..+....+..........++....
AQUILEGIA TRITERNATA	....+..+..................1.1+......
AQUILEGIA SPP.	.....+..+++..................................+..
ARENARIA SPP.	....+.+.+.
ARENARIA LANUGINOSA	.....+..P.......+....................+.......
ARNICA CORDIFOLIA	.........+...2..++.1+.2...+2..+1.111.122211221.1222+212121122..
ARNICA MOLLIS	....................................1+...............+...+..
ARTEMISIA FRANSERIOIDES	....P.+...+......++..........11.......1.1.....
BISTORTA BISTORTOIDES	.........+..+++................P...................+.+...
BISTORTA VIVIPARA	........+...+.......1+..................1.....+.+........1...
CAMPANULA ROTUNDIFOLIA	..........+...+.....+.....+.................++
CAREX LEUCODONTA	.........1...1.....1+.........1.................1+....+...2..
CASTILLEJA MINIATA	............+......+..............+...............+...
CASTILLEJA SPP.	....P...........P..............+...
CHAMERION ANGUSTIFOLIUM	+....P+.+++P.+.++...+...+.+..+..+1++.P.+.+.....++++......++++.....+..+...+P.........+.........+......
CIRSIUM SPP.	.................P...+.......................+.....
CLEMATIS COLUMBIANA	...++...++......1.+.....P..................
CLEMENTSIA RHODANTHA	.........1+...+...
CORALLORHIZA MACULATA	....P...+..........++.........+..+......
CORALLORHIZA SPP.	....+..............+.P.............
CYSTOPTERIS FRAGILIS	P........+......+.................................+...................+..P..P........+.......1.....P.
DELPHINIUM BARBEYI	...................+...................+..P++......1..++..
DISPORUM TRACHYCARPUM	....+...P...+.+...................+......
DRABA AUREA	...............+....................................+...
DRABA HELLERIANA	..+.....+.++.+.+..+......+P..+........+.........+...
DUGALDIA HOOPESII	....21+11+1.+.1+1+.P+11.+.......+.P..+..P
ERIGERON CONCINNUS	......................................+.....................+..
ERIGERON COULTERI	...........1......11....................................+...
ERIGERON EXIMIUS	.+1..++.........11.1.1.....1..+1.11.2.2.1+222+..1.2+.11.11..1+++P+P+.++P.+111P12++++.+..+..212+22.2..
ERIGERON FORMOSISSIMUS	....+..................1...
ERIGERON SPP.	....+
ERIGERON MELANOCEPHALUS	.........+..1......+...............+..
ERIGERON PEREGRINUS	.........+...1.....+..1..........2..........1....+..1...
ERYTHRONIUM GRANDIFLORUM	....++...........+..
FRAGARIA AMERICANA	...................+..........+...............+.....................2.+11.222......+...+2.......1..
FRAGARIA OVALIS	+..++..++.1....+++11.+1.1.....+.++.1.P++++++....+.1.+.+.....+11+.++11+++11111+11.11++++........1+211..+
FRASERA SPECIOSA	....................................+........................P.+............+.............1...
GALIUM TRIFLORUM	....++..........................
GENTIANELLA AMARELLA S. ACUTA	....+....+++.+.......+..............+..
GENTIANELLA AMARELLA S. HETERO.	.................................+.......+....+..
GERANIUM CAESPITOSUM	....1....+..........
GERANIUM RICHARSONII	2..................+...P...+......++1.1+1+.1+...+.+..11.1.+11.P.+..+++11+211+1111++++.+....+1121+11+2+P
GOODYERA OBLONGIFOLIA	.................+.....+P+.++..+..+..+.....++....+......+....+.......+.+++.P++.P....++++...+.+.+++........

TABLE B.1 (CONTINUED) — PICEA ENGELMANNII SERIES

HABITAT TYPE NUMBER:	10000000000000000000000000000000000000000000000000000000000000000000000000000000000000001111111100
	25335531111111111111111122222222222222222222222222222222222222222222222555555555555555555556666660000000000099
PHASE NUMBER:	11111111111111111111112222222222222222222222222222222222222222222222221111111111122222222222211111111111111
PRINCIPLE INVESTIGATOR:	MFAMMMEMLMMMLLMLLMLLLLMMMLLMMLLMLLLLLLLLLLLLLLMLLLLLLLLLLLLLLLMMMMMMMMMMMMMMMMMMMMMMMMMMMMDDDEMMMMMMMEMM
GEOGRAPHIC LOCATION:	MCCCCCMNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNCCCGGGGGGGGGGGGGGGGGGGGLLKKKKHGGGGGGMKK
PLOT NUMBER:	5907771111110211102210011221120122221100011111122220111101117771211101051212105111122400005566002044
	4515333027552726995249544218446544524729796661441146951429551253394888070495859078896000005947558 86900
	7711951680172782514815565575834940077706533085791692461752561865364798895862595336019868949079601240 1
GOODYERA REPENS	....+++.........++...........................
HALENIA RECURVA	....+.+.+...+.P..+..P.................
HELIANTHELLA QUINQUENERVIS	....+....+.P...................+.....
HERACLEUM SPHONDYLIUM	................P...
HIERACIUM GRACILE	.......+...+...........+..+......+..........+.......+..
LATHYRUS ARIZONICUS	.++..............1..1...+1.+P+.P121.+112++++.1..+.++11+++5+++
LIGULARIA AMPLECTENS	.......1.2.22+1+...2++.1..211+.2.12+1..1.....52++112..1..21.......................................
LIGULARIA BIGELOVII	..........+...P+..P......P+.......+.+....+......+
LITHOSPERMUM MULTIFLORUM	....+........++..............+.....
LIGUSTICUM PORTERI	......++.P.......+.+..1.+.1..+.....1.1+1.121+.1..11.11.1..+++...P..+.+...+..+.P....+++++.++.11.P....
MERTENSIA CILIATA	.......+...+++....11++.P..+.....+.1+2..++....+.21..2+11....+++....................................
MERTENSIA FRANCISCANA	+..1.....+1++..+...............+.++
MITELLA PENTANDRA	...........................+......1............P..+.+.....1......................................
OREOCHRYSUM PARRYI	1..P+...+.1....++1+..+..+....++1.1....+11++11+...++..21.++.12++..........+......1....11......11+.1.1.++
OREOXIS ALPINA	..........+...1...............................+...
OSMORHIZA DEPAUPERATA	..........+1.....1...+.+.1......1++11.1+1++++.+.1+1++.1.1++...+++++.....++.P+P+..++.+.....+++.PP.....
OXALIS METCALFEI	....P......1......+...............+.......
OXYPOLIS FENDLERI	..........+.++........................P.....+...+...
PEDICULARIS BRACTEOSA	....................................++.........+...++...
PEDICULARIS RACEMOSA	.......+.+........+....11+.211+1+.2.+11+21.21.11..+++1121.1+1......................................
PEDICULARIS GRAYI	....P..........+....+.....
PENSTEMON BRIDGESII	..............................+.........+.............+..
PENSTEMON WHIPPLEANUS	.........+.1....+.P.....................P..............P.P..+......................................
POLEMONIUM PULCHERRIMUM	+......1+1+5211++112+11+1+2++++1+1+2122.11112221+2112112+221.......................................
POTENTILLA DIVERSIFOLIA	.......+..+.............+.+...+.. ....
POTENTILLA GRACILIS V PULCHER	...........++....++.................+....+...1.....
PRIMULA PARRYI	+.........+...........+.........................+...
PRUNELLA VULGARIS	....+...+.......P+.......................
PSEUDOCYMOPTERIS MONTANUS	+.+.+.P++..+++.++.1+..+.+.+.+++.++.+.++1++.1..++.++.+++++....PPPP..+..P1..+1+..++..++P++++++1.111++.
PSEUDOSTELLARIA JAMESIANA	....+..+.........................1................
PTERIDIUM AQUILINUM	....12112..2+.21+1+111P+..+.1++11....11..
PYROLA CHLORANTHA	...++...+P++P++++.P++++++.+...+....+..++...+.+..
RAMISCHIA SECUNDA	+++..+..+++...+.+...+.1.++++..1..+.+1+.1+++++..+.++1++.1++.++++++++.+1++++.+1++.+.++P.....+.1+......
RANUNCULUS ESCHSCHOLTZII	..................+1+...........................+.........+..
RHODIOLA INTEGRIFOLIA	............1+.....+...........................1.......+..
SAXIFRAGA BRONCHIALIS	........+1+..............+..+...
SAXIFRAGA RHOMBOIDEA	..........++.+..+.......................+...
SEDUM LANCEOLATUM	..........+....+..
SENECIO ATRATUS	....
SENECIO CARDAMINE	....2P252525121522115112...................
SENECIO NEOMEXICANUS	...................+..............+...+.....
SENECIO SANGUISORBOIDES	...........+..+.......+.........................+.................................+1...............
SENECIO WOOTONI	....P...+1+.2++..++1+1.+1.1P.P...2..+.++.++.
SIBBALDIA PROCUMBENS	.......+.+++.+....+1....+......P...................+..

TABLE B.1 (CONTINUED) — PICEA ENGELMANNII SERIES

HABITAT TYPE NUMBER:	10000000000000000000000000000000000000000000000000000000000000000000000000000000000000001111111100
	25335531111111111111111122222222222222222222222222222222222222222222222555555555555555555556666660000000000099
PHASE NUMBER:	11111111111111111111112222222222222222222222222222222222222222222222221111111111122222222222211111111111111
PRINCIPLE INVESTIGATOR:	MFAMMMEMLMMMLLMLLMLLLLMMMLLMMLLMLLLLLLLLLLLLLLMLLLLLLLLLLLLLLLMMMMMMMMMMMMMMMMMMMMMMMMMMMMDDDEMMMMMMMEMM
GEOGRAPHIC LOCATION:	MCCCCCMNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNCCCGGGGGGGGGGGGGGGGGGGGLLKKKKHGGGGGGMKK
PLOT NUMBER:	5907771111110211102210011221120122221100011111122220111101117771211101051212105111122400005566002044
	4515333027552726995249544218446544524729796661441146951425512533394888070495859078896000005947558 86900
	7711951680172782514815565575834940077706533085791692461752561865364798895862595336019868949079601240 1
SMILACINA RACEMOSA	...+.....................1............+......................++++...++..P+.+P....+.++..++...+ ...+..
SMILACINA STELLATA	.+++..++.+...+..+.P.1.+1+.++...1+++2..P1..
SOLIDAGO SPP.	....1.1...+.....2.+................
STELLARIA LONGIPES	...........++..+.++.........................+.........+..........................+..........
STREPTOPUS AMPLEXIFOLIUS	..........................+......1.......P+......1..+....+...
TARAXACUM OFFICINALE	..............+...+...+..
TARAXACUM SPP.	....++......P+...............
THALICTRUM FENDLERI	..............+...................+.................1.....+.....++.++.1..+1.11+1+...++..+.1+2+.1111..
THERMOPSIS DIVARICARPA	....1..51..2P...............2.....
THLASPI MONTANUM V. MONTANUM	.......+..+.+....+++..P....+........++...........P.+...
TOWNSENDIA FORMOSA	....++...............+.....
TRAUTVETTERIA CAROLINENSIS	......................................5.......4..
TRIFOLIUM BRANDEGEI	....................2.......1........1..................2..
TRIFOLIUM DASYPHYLLUM	.......+5..........................+..
TROLLIS LAXIS	...........+.......+...............+...............+...1...
VALERIANA CAPITATA	...................................++..........+...............................+...............2.......
VERATRUM CALIFORNICUM	...................+.....+........P..............+...
VERONICA WORMSKJOLDII	.......+....+1......+1.....+..........+...........+....+...+..
VICIA AMERICANA	.................P..................................1.........++..P..+P..1.++1..++....+.+++.1++11+++
VIOLA CANADENSIS	.+.+...............1.......+...................++......++.++.....+1+1.+1++1+1+1111+1+2111+++++P+..211++1.+..
ZYGADENUS SPP.	..........+............+...+..........++.++..................
ZYGADENUS ELEGANS	...P++..........+.........++....+.+.....+++++P+......+..++.+..P++.+P...................................++......

TABLE B.1 (CONTINUED) — PICEA ENGELMANNII SERIES

HABITAT TYPE NUMBER:	000011100000000
	777711188888888
PHASE NUMBER:	11111111111111
PRINCIPLE INVESTIGATOR:	MMMMLLLLLLLLLL
GEOGRAPHIC LOCATION:	LLLLNNNNNNNNNNN
PLOT NUMBER:	222212001111122
	535557790225925
	642177710689685
- - T R E E S - -	....
ABIES CONCOLOR - VNG REGEN.	......4........
ABIES CONCOLOR - ADV REGEN	......5........
ABIES CONCOLOR - MATURE	......1........
ABIES LASIOCARPA - VNG REGEN	..4.4+.....+..P
ABIES LASIOCARPA - ADV REGEN	..422..+1.+....
ABIES LASIOCARPA - MATURE	..2+2..1+..P...
PICEA ENGELMANNII - VNG REGEN	7454+3++2+1+252
PICEA ENGELMANNII - ADV REGEN	434533321522151
PICEA ENGELMANNII - MATURE	524253+5.122124
PINUS PONDEROSA - ADV REGEN	....
PINUS PONDEROSA - MATURE	....
PICEA PUNGENS - VNG REGEN	......2........
PICEA PUNGENS - ADV REGEN	......5........
PICEA PUNGENS - MATURE	......1........
PINUS STROBIFORMIS - VNG REGEN	.3.............
PINUS STROBIFORMIS - ADV REGEN	.2.............
PINUS STROBIFORMIS - MATURE	.+.............
POPULUS ANGUSTIFOLIA-ADV REGEN	....2+5........
POPULUS ANGUSTIFOLIA-MATURE	....112........
POPULUS TREMULOIDES- VNG REGEN	.......55.....5
POPULUS TREMULOIDES- ADV REGEN	2......24.....+
POPULUS TREMULOIDES - MATURE	5..+...........
PSEUDOTSUGA MENZIESII-VNG REGE	3.2...4........
PSEUDOTSUGA MENZIESII-ADV REGE	...+..1........
PSEUDOTSUGA MENZIESII - MATURE	3425..1.......2
- - S H R U B S - -	....
ACER GLABRUM	1.1P..2........
ALNUS TENUIFOLIA	....14.........
CHIMAPHILA UMBELLATA	......+........
HOLODISCUS DUMOSUS	21.1...........
JAMESIA AMERICANA	1+.2..........1
JUNIPERUS COMMUNIS	.......2211P+.1
LONICERA ARIZONICA	....
LONICERA INVOLUCRATA	....222.+......
LONICERA UTAHENSIS	....
MONESES UNIFLORA	....
PACHISTIMA MYRSINITES	......2........
PHYSOCARPUS MONOGYNUS	....
POPULUS TREMULOIDES - SHRUBS	2+++...11.....1
POTENTILLA FRUTICOSA	.............+1.
RIBES SPP.	....
RIBES MONTIGENUM	....21...++.+.1
RIBES PINETORUM	1..............

TABLE B.1 (CONTINUED) — PICEA ENGELMANNII SERIES

HABITAT TYPE NUMBER:	000011100000000
	777711188888888
PHASE NUMBER:	11111111111111
PRINCIPLE INVESTIGATOR:	MMMMLLLLLLLLLL
GEOGRAPHIC LOCATION:	LLLLNNNNNNNNNNN
PLOT NUMBER:	222212001111122
	535557790225925
	642177710689685
RIBES WOLFII	1..11..1+.P1...
ROBINIA NEOMEXICANA	....
ROSA SPP.	....+.+.......2
RUBUS IDAEUS VAR. STRIGOSUS	........+PP....
RUBUS PARVIFLORUS	......+........
SALIX SPP.	......+........
SAMBUCUS RACEMOSA	....2.....P....
SALIX SCOULERIANA	....
SWIDA SERICEA	....2.1........
SYMPHORICARPOS OREOPHILUS	....+.1........
VACCINIUM MYRTILLUS	......+..++....
- - G R A M I N O I D S - -	....
AGROPYRON TRACHYCAULUM	....++.........
AGROSTIS ALBA	....++.........
BROMUS CILIATUS	+PP.111...+...+
CAREX BELLA	....
CAREX BREVIPES	....
CAREX FOENEA	.....1.........
CAREX GEYERI	.......1..+....
CAREX ROSSII	+++..+.+++++++1
DESCHAMPSIA CAESPITOSA	....
ELYMUS TRITICOIDES	221P...........
FESTUCA ARIZONICA	....
FESTUCA OVINA	.....+.++++.++.
FESTUCA SORORIA	....
FESTUCA THURBERI	.......+..+..1.
KOELERIA PYRAMIDATA	........+.+.++.
LUZULA PARVIFLORA	..P............
MUHLENBERGIA VIRESCENS	....
POA ALPINA	....
POA FENDLERIANA	........+...+.+
POA LEPTOCOMA	....
POA PRATENSIS	.....+.........
POA REFLEXA	....
SITANION HYSTRIX	....
TRISETUM SPICATUM	........+++++++
TRISETUM SPICATUM S. MONTANUM	+1+..+.........
- - F O R B S - -	....
ACHILLEA MILLEFOLIUM	....++.......+.
ACOMASTYLIS ROSSII	....
ACONITUM COLUMBIANUM	.....+.........
ACTAEA RUBRA SSP. ARGUTA	....+++........
ANGELICA GRAYII	....
ANTENNARIA ROSULATA	......+...+..+.

TABLE B.1 (CONTINUED) — PICEA ENGELMANNII SERIES

HABITAT TYPE NUMBER:	000011100000000
	777711188888888
PHASE NUMBER:	11111111111111
PRINCIPLE INVESTIGATOR:	MMMMLLLLLLLLLL
GEOGRAPHIC LOCATION:	LLLLNNNNNNNNNNN
PLOT NUMBER:	222212001111122
	535557790225925
	642177710689685
AQUILEGIA CAERULEA	........+.P....
AQUILEGIA ELEGANTULA	..+...+........
AQUILEGIA TRITERNATA	....
AQUILEGIA SPP.	....
ARENARIA SPP.	....
ARENARIA LANUGINOSA	....
ARNICA CORDIFOLIA	1
ARNICA MOLLIS	....
ARTEMISIA FRANSERIOIDES	+.....+........
BISTORTA BISTORTOIDES	....
BISTORTA VIVIPARA	....
CAMPANULA ROTUNDIFOLIA	........+....+.
CAREX LEUCODONTA	....
CASTILLEJA MINIATA	....
CASTILLEJA SPP.	....
CHAMERION ANGUSTIFOLIUM	...++++........
CIRSIUM SPP.	....++.........
CLEMATIS COLUMBIANA	P..............
CLEMENTSIA RHODANTHA	....
CORALLORHIZA MACULATA	.....+.........
CORALLORHIZA SPP.	....
CYSTOPTERIS FRAGILIS	............+..
DELPHINIUM BARBEYI	....
DISPORUM TRACHYCARPUM	......+........
DRABA AUREA	............+..
DRABA HELLERIANA	....
DUGALDIA HOOPESII	....+..........
ERIGERON CONCINNUS	....22.........
ERIGERON COULTERI	....
ERIGERON EXIMIUS	+.1.111...P...2
ERIGERON FORMOSISSIMUS	........+......
ERIGERON SPP.	.+.........+...
ERIGERON MELANOCEPHALUS	....
ERIGERON PEREGRINUS	....
ERYTHRONIUM GRANDIFLORUM	....
FRAGARIA AMERICANA	1.++..2.+.....1
FRAGARIA OVALIS	....11..++P....
FRASERA SPECIOSA	....
GALIUM TRIFLORUM	....+1+........
GENTIANELLA AMARELLA S. ACUTA	....
GENTIANELLA AMARELLA S. HETERO	....
GERANIUM CAESPITOSUM	+..............
GERANIUM RICHARSONII	..P.212.+......
GOODYERA OBLONGIFOLIA	......+........

TABLE B.1 (CONTINUED) — PICEA ENGELMANNII SERIES

HABITAT TYPE NUMBER:	000011100000000
	777711188888888
PHASE NUMBER:	11111111111111
PRINCIPLE INVESTIGATOR:	MMMMLLLLLLLLLL
GEOGRAPHIC LOCATION:	LLLLNNNNNNNNNNN
PLOT NUMBER:	222212001111122
	535557790225925
	642177710689685
GOODYERA REPENS	....
HALENIA RECURVA	....
HELIANTHELLA QUINQUENERVIS	....
HERACLEUM SPHONDYLIUM	....12+.+......
HIERACIUM GRACILE	....
LATHYRUS ARIZONICUS	+..............
LIGULARIA AMPLECTENS	....
LIGULARIA BIGELOVII	....++.........
LITHOSPERMUM MULTIFLORUM	....
LIGUSTICUM PORTERI	....++.........
MERTENSIA CILIATA	....2++........
MERTENSIA FRANCISCANA	....
MITELLA PENTANDRA	....
OREOCHRYSUM PARRYI	....1.1.......1
OREOXIS ALPINA	....
OSMORHIZA DEPAUPERATA	....+21........
OXALIS METCALFEI	....
OXYPOLIS FENDLERI	.....1.........
PEDICULARIS BRACTEOSA	....
PEDICULARIS RACEMOSA	......1...+....
PEDICULARIS GRAYI	....+.+........
PENSTEMON BRIDGESII	....
PENSTEMON WHIPPLEANUS	....
POLEMONIUM PULCHERRIMUM	....
POTENTILLA DIVERSIFOLIA	....
POTENTILLA GRACILIS V PULCHER	............+..
PRIMULA PARRYI	....
PRUNELLA VULGARIS	....
PSEUDOCYMOPTERIS MONTANUS	....+++.+++.+..
PSEUDOSTELLARIA JAMESIANA	....
PTERIDIUM AQUILINUM	....
PYROLA CHLORANTHA	....
RAMISCHIA SECUNDA	..+P.++........
RANUNCULUS ESCHSCHOLTZII	....
RHODIOLA INTEGRIFOLIA	....
SAXIFRAGA BRONCHIALIS	.........1++P+.+
SAXIFRAGA RHOMBOIDEA	....
SEDUM LANCEOLATUM	.............++.
SENECIO ATRATUS	........+2+P1...
SENECIO CARDAMINE	....
SENECIO NEOMEXICANUS	............+..
SENECIO SANGUISORBOIDES	....
SENECIO WOOTONI	......+........
SIBBALDIA PROCUMBENS	....

TABLE B.1 (CONTINUED) — PICEA ENGELMANNII SERIES

HABITAT TYPE NUMBER:	000011100000000
	777711188888888
PHASE NUMBER:	11111111111111
PRINCIPLE INVESTIGATOR:	MMMMLLLLLLLLLL
GEOGRAPHIC LOCATION:	LLLLNNNNNNNNNNN
PLOT NUMBER:	222212001111122
	535557790225925
	642177710689685
SMILACINA RACEMOSA	....+1+........
SMILACINA STELLATA	+.+.1++........
SOLIDAGO SPP.	....
STELLARIA LONGIPES	....
STREPTOPUS AMPLEXIFOLIUS	.....+.........
TARAXACUM OFFICINALE	.....++........
TARAXACUM SPP.	....
THALICTRUM FENDLERI	....212.+......
THERMOPSIS DIVARICARPA	....
THLASPI MONTANUM V. MONTANUM	.....+.........
TOWNSENDIA FORMOSA	....
TRAUTVETTERIA CAROLINENSIS	.....+.........
TRIFOLIUM BRANDEGEI	....
TRIFOLIUM DASYPHYLLUM	....
TROLLIS LAXIS	....
VALERIANA CAPITATA	....
VERATRUM CALIFORNICUM	....
VERONICA WORMSKJOLDII	....
VICIA AMERICANA	+P.............
VIOLA CANADENSIS	+.P.112........
ZYGADENUS SPP.	....
ZYGADENUS ELEGANS	....

APPENDIX C

Consolidated Series Site Characteristics Tables

There are 11 consolidated series site characteristics tables for southwestern habitat types, one for each climax tree series (tables C.1—C.11). Each series table contains subtables for each habitat type within the series. Each subtable gives the habitat type name and number and contains site information on individual plots with the habitat type. Plots are identified by a five-digit code of the Principal Investigator responsible for the plot, the general Geographic Location, and the Plot Number assigned by the principal investigator.

The Principal Investigator codes are:

Code	Principal investigator
A	Alexander, Billy G.
E	Muldavin, Esteban H.
F	Fitzhugh, E. Lee
D	DeVelice, Robert L.
L	Ludwig, John A.
M	Moir, William H.
W	White, Alan S.

The Geographic Location codes are:

Code	Location
C	Cibola National Forest, central New Mexico.
G	Gila National Forest, southwestern New Mexico, Apache National Forest, eastern Arizona.
H	Hualapai Indian Reservation, northwest Arizona.
K	Coronado National Forest, southeastern Arizona.
L	Lincoln National Forest, south-central New Mexico.
M	Mogollòn Plateau, including the Coconino, Apache-Sitgreaves, and Kaibab National Forests of northern Arizona.
N	Northern New Mexico and southern Colorado, including the Santa Fe, Carson, San Isabel, San Juan, and Rio Grande National Forests.
P	Prescott National Forest, west-central Arizona.
S	San Carlos Indian Reservation, central Arizona.
T	Tonto National Forest, central Arizona.
W	Fort Apache Indian Reservation (White River), east-central Arizona.

Site characteristics, given as provided by the original principal investigators, include:

1. Geographic locale—the approximate location of the plot.
2. USGS topographic quadrangle along with township, range, section, and quarter section location, if given.
3. Elevation—meters and feet.
4. Percent slope.
5. Aspect—degrees azimuth, and a cosine conversion of azimuth where 2.0 = northeast (coolest) and 0.0 = southwest (warmest).
6. Land form code as follows:

0 = plateau	4 = lower slope
1 = ridge	5 = bench
2 = upper slope	6 = streamside
3 = midslope	7 = other

Two or more numbers together imply transitions.

7. Percent of plot that is exposed soil.
8. Percent of plot that is covered by rock.
9. Underlying geologic parent material (codes assigned by principal investigator).

TABLE C.2 -- SITE CHARACTERISTICS -- PICEA ENGELMANNII SERIES

PICEA ENGELMANNII/GEUM ROSSII HT

HT NUMBER: 12 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	ELEVATION (FT)	SLOPE (%)	ASPECT DEG	ASPECT COS	LAND FORM	% COVER SOIL	% COVER ROCK	PARENT MATERIAL
MM347	AZ	SAN FRAN MTNS	S FRAN AGASSIZ PK	HUMPHREY PEAK					3398	11150	55	350	1.57	2	0	40	

PICEA ENGELMANNII/MOSS HT

HT NUMBER: 03 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	ELEVATION (FT)	SLOPE (%)	ASPECT DEG	ASPECT COS	LAND FORM	% COVER SOIL	% COVER ROCK	PARENT MATERIAL
FC937	NM	MNT. TAYLOR	MT TAYLOR	MNT TAYLOR	12N	7W	19	SE	3194	10480	20	322	1.12	12	0	0	ANDESIT
AC 11	NM	MNT TAYLOR	LAMOSCA PEAK	SAN MATEO	12N	7W	20	NW	3267	10720	8	18	1.89	12	0	T	BASALT
MC731	NM	SAN MATEO MTS	APACHE KID PEAK	BLUE MOUNTAIN	8S	6W	2		2974	9760	25	280	0.43	2	0	4	
MC739	NM	SAN MATEO MTS	TEEPEE PEAK	BLUE MOUNTAIN	7S	6W	26		3038	9970	4	18	1.89	1	0	2	
MC735	NM	SAN MATEO MTS	WEST BLUE MOUNTAIN	BLUE MOUNTAIN	7S	6W	34		3108	10200	45	0	1.71	2	0	1	
EW101	AZ	WHITE MTS	MT WARREN						3243	10640	4	168	0.46	1	0	5	BASALT

PICEA ENGELMANNII/VACC. MYRTILLUS/POLE. PULCHERRIMUM HT, PIEN PH

HT NUMBER: 01 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	ELEVATION (FT)	SLOPE (%)	ASPECT DEG	ASPECT COS	LAND FORM	% COVER SOIL	% COVER ROCK	PARENT MATERIAL
MN126	NM	SANGRE RANGE	GOLD HILL TRAIL	WHEELER PK.					3505	11500	5	10	1.82	1	0	0	
LN178	CO	SPANISH PEAKS	1 MI W BEAR LAKE CG	TRINCHERA PEAK					3633	11920	48	105	1.50	2	T	1	
MN150	NM	SANGRE RANGE	NO FISH LAKE BASIN	PECOS FALLS					3596	11800	72	20	1.91	2	T	20	QRTZITE
MN151	NM	SANGRE RANGE	CHIMAYOSOS PEAK	PECOS FALLS					3596	11800	50	225	0.00	3	T	15	TALUS
MN127	NM	SANGRE RANGE	GOLD HILL TRAIL	RED RIVER					3596	11800	20	103	1.53	2	0	0	
LN 72	CO	SAN JUAN MTS	ELWOOD PASS SLOPES	ELWOOD PASS	37N	1E	34	SE	3590	11780	19	282	0.46	2	0	T	RHYOLIT
LN227	CO	SANGRE RANGE	LAKE COMO	TWIN PEAKS					3596	11800	10	10	1.82	3	T	3	
MN168	NM	SANGRE RANGE	N FORK TESUQUE CR.	ASPEN BASIN					3627	11900	40	310	0.91	2	0	6	
LN192	CO	WET MTS	CISNEROS CREEK	SAN ISABEL					3438	11280	32	245	0.06	3	T	35	
LN193	CO	WET MTS	POLE CREEK TRAIL	SAN ISABEL					3383	11100	17	350	1.57	3	T	T	
MN 31	NM	SANGRE RANGE	CERRO VISTA	CERRO VISTA					3413	11200	54	105	1.50	2	0	1	

TABLE C.2 (CONTINUED) -- SITE CHARACTERISTICS -- PICEA ENGELMANNII SERIES

PICEA ENGELMANNII/VACC. MYRTILLUS/POLE. PULCHERRIMUM HT, PIEN PH (CONTINUED)

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	ELEVATION (FT)	SLOPE (%)	ASPECT DEG	ASPECT COS	LAND FORM	% COVER SOIL	% COVER ROCK	PARENT MATERIAL
LN224	CO	SANGRE RANGE	HUERFANO RIVER	BLANCA PEAK					3340	10960	35	105	1.50	4	1	10	
LN248	CO	SAN JUAN MTS	SCHINZEL FLATS	ELWOOD PASS					3529	11580	13	350	1.57	3	T	0	
LN191	CO	WET MTS	BLUE LAKES	SAN ISABEL					3450	11320	14	335	1.34	3	0	0	
LN 53	CO	SAN JUAN MTS	GRAYBACK MT	SUMMITVILLE	37N	4E	10	NE	3572	11720	46	95	1.64	3	1	2	ANDESIT

PICEA ENGELMANNII/VACC. MYRTILLUS/POLE. PULCHERRIMUM HT, ABLA PH

HT NUMBER: 02 PHASE NUMBER: 02

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	ELEVATION (FT)	SLOPE (%)	ASPECT DEG	ASPECT COS	LAND FORM	% COVER SOIL	% COVER ROCK	PARENT MATERIAL
MN 45	NM	SANGRE RANGE	SERPENT LAKE TRAIL	JICARITA PK					3520	11550	20	10	1.82	12	0	0	
MN146	NM	SANGRE RANGE	NO FISH LAKE BASIN	PECOS FALLS					3535	11600	28	270	0.29	1	0	7	MORAINE
MN125	NM	SANGRE RANGE	GOLD HILL TRAIL	WHEELER PK.					3438	11280	38	82	1.80	2	0	T	
LN215	CO	SANGRE RANGE	COMANCHE TRAIL	HORN PEAK					3352	11000	46	345	1.50	2	T	1	
LN287	CO	SAN JUAN MTS	WOLF CREEK	WOLF CK PASS					3108	10200	42	355	1.64	3	0	1	
MN145	NM	SANGRE RANGE	NO FISH LAKE BASIN	PECOS FALLS					3499	11480	37	165	0.50	3	0	7	
MN148	NM	SANGRE RANGE	NO FISH LAKE BASIN	PECOS FALLS					3474	11400	28	345	1.50	2	0	2	TALUS
LN263	CO	SAN JUAN MTS	TRUJILLO MEADOWS	CUMBRES					3255	10680	48	275	0.36	34	T	1	
LN 54	CO	SAN JUAN MTS	W FORK PINOS CREEK	SUMMITVILLE	37N	4E	4	SE	3425	11240	16	10	1.82	3	0	T	RHY-AND
MN149	NM	SANGRE RANGE	NO FISH LAKE BASIN	PECOS FALLS					3474	11400	30	315	1.00	2	0	7	TALUS
LN244	CO	SAN JUAN MTS	S FORK ROCK CREEK	JASPER					3459	11350	39	75	1.87	3	T	5	
LN250	CO	SAN JUAN MTS	PLATORO RESERVOIR	PLATORO					3124	10250	36	20	1.91	3	T	T	
LN220	CO	SANGRE RANGE	SOUTH COLONY LAKES	CRESTONE PEAK					3560	11680	20	125	1.17	2	T	10	
LN247	CO	SAN JUAN MTS	HORSETHIEF PARK	SUMMIT PEAK					3297	10820	23	240	0.03	4	T	T	
LN177	CO	SPANISH PEAKS	N FORK PURGATOIRE R	TRINCHERA PEAK					3310	10860	30	55	1.98	3	0	T	
LN127	CO	LA PLATA MTNS	SHRKTOOTH TRAIL HD	LA PLATA	37N	11W	20	NW	3331	10930	25	15	1.87	3	0	T	GRANITE
LN 90	CO	SAN MIGUEL MTNS	SLP S OF MIDDLE PK	DOLORES PARK	41N	11W	6	SW	3389	11120	23	210	0.03	2	T	1	GRANITE
LN 76	CO	SAN JUAN MTS	PASS CK BELOW CAMPO	ELWOOD PASS	38N	2E	2	SW	3035	9960	55	1	1.72	4	0	0	ANDESIT
LN 93	CO	SAN MIGUEL MTNS	W FK UP LTL FISH CK	GROUNDHOG MT	41N	12W	18	NE	3371	11060	40	20	1.91	2	T	7	GRN-SHL
LN163	CO	SAN JUAN MTNS	W SPUR MILLER MT	LEMON RESV	37N	7W	22	SW	3304	10840	37	307	0.86	2	2	T	LIMSTON
LN160	CO	SAN JUAN MTNS	RUNLETT PARK	VALLECITO RESV	37N	6W	11	NW	3255	10680	40	326	1.19	3	T	T	LIM-SHL
LN168	CO	SAN JUAN MTNS	CAMP CREEK	MT VIEW CREST	38N	8W	25	NE	3297	10820	65	342	1.45	3	T	1	LIMSTON
LN115	CO	LA PLATA MTNS	LITTLE BEAR CK	ORPHAN BUTTE	38N	11W	20	SW	3285	10780	25	350	1.57	1	T	T	SANDSTN
MN147	NM	SANGRE RANGE	NO FISH LAKE BASIN	PECOS FALLS					3474	11400	42	10	1.82	3	0	9	
LN149	CO	RICO MTNS	BOLAM PASS	HERMOSA PK	40N	9W	19	SE	3176	10420	26	85	1.77	2	T	2	QRT-SAN
LN211	CO	SANGRE RANGE	MIDDLE TAYLOR CREEK	ELECTRIC PEAK					3291	10800	36	350	1.57	34	T	15	
LN216	CO	SANGRE RANGE	COMANCHE LAKE	HORN PEAK					3480	11420	30	90	1.71	3	T	3	
LN249	CO	SAN JUAN MTS	GLOBE CREEK	PLATORO					3139	10300	53	350	1.57	4	0	0	
LN262	CO	SAN JUAN MTS	TRUJILLO MEADOWS	CUMBRES					3243	10640	48	35	1.98	4	T	0	
LN 94	CO	SAN MIGUEL MTNS	BLACK MESA UP SLPS	GROUNDHOG MT	41N	12W	22	NW	3395	11140	23	335	1.34	2	T	1	GRANITE
LN136	CO	LA PLATA MTNS	WIELAND GULCH RV	LA PLATA	37N	11W	35	NE	3115	10220	25	245	0.06	4	T	1	GRANITE
LN111	CO	RICO MTNS	HIGHLINE TRAIL	HERMOSA PK	39N	10W	21	SW	3285	10780	50	285	0.50	2	1	T	SANDSTN
LN147	CO	RICO MTNS	BOLAM PASS	HERMOSA PK	40N	9W	19	SE	3474	11400	13	60	1.97	2	T	1	QRT-SAN
LN125	CO	LA PLATA MTNS	BEAR CK	ORPHAN BUTTE	37N	11W	6	NW	3236	10620	78	340	1.42	23	1	1	SANDSTN

TABLE C.2 (CONTINUED) -- SITE CHARACTERISTICS -- PICEA ENGELMANNII SERIES

PICEA ENGELMANNII/VACC. MYRTILLUS/POLE. PULCHERRIMUM HT, ABLA PH (CONTINUED)

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	(FT)	SLOPE (%)	ASPECT DEG	COS	LAND FORM	% COVER SOIL	ROCK	PARENT MATERIAL
LN 52	CO	SAN JUAN MTS	NW OF FUCHS RESV	SUMMITVILLE	37N	4E	3	NE	3432	11260	43	295	0.66	34	T	1	RHY-AND
LN153	CO	SAN MIGUEL MTNS	MILL CK	SILVERTON	42N	8W	27	NE	3200	10500	53	335	1.34	4	0	T	QRT-SAN
LN116	CO	LA PLATA MTNS	UP ROUGH CANYON	ORPHAN BUTTE	38N	11W	16	SW	3425	11240	60	75	1.87	34	5	4	SANDSTN
LN121	CO	RICO MTNS	UPPER PRIEST GULCH	CLYDE LAKE	39N	12W	1	SW	3310	10860	61	115	1.34	3	1	1	SANDSTN

PICEA ENGELMANNII/VACCINIUM MYRTILLUS HT

HT NUMBER: 02 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	(FT)	SLOPE (%)	ASPECT DEG	COS	LAND FORM	% COVER SOIL	ROCK	PARENT MATERIAL
MC738	NM	SAN MATEO MTS	8BLUE MOUNTAIN	BLUE MOUNTAIN	7S	6W	35		306	1004	3	235	0.02	0	6	0	7
MC736	NM	SAN MATEO MTS	CUB SPRING	BLUE MOUNTAIN	7S	6W	27		2865	9400	31	3	1.74	7	0	T	
MC733	NM	SAN MATEO MTS	BLUE MOUNTAIN	BLUE MOUNTAIN					3093	10150	60	47	2.00	2	0	1	

PICEA ENGELMANNII/SENECIO CARDAMINE HT, ABIES LASIOCARPA PH

HT NUMBER: 05 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	(FT)	SLOPE (%)	ASPECT DEG	COS	LAND FORM	% COVER SOIL	ROCK	PARENT MATERIAL
MG193	AZ	WHITE MTS	HANNAGAN CR						2779	9120	23	334	1.33	2	0	T	BASALT
MG246	AZ	WHITE MTS	KP CIENEGA						2804	9200	27	97	1.62	2	0	1	
MG184	AZ	WHITE MTS	E FORK THOMAS CR						2743	9000	2	50	2.00	1	T	0	BASALT
MG187	AZ	WHITE MTS	HANNAGAN CR						0	0	0	0	1.71	0	0	0	BASALT
MG189	AZ	WHITE MTS	RENO LO ROAD						2804	9200	15	88	1.73	12	0	0	BASALT
MG 8	AZ	WHITE MTS	E FORK THOMAS CR						2743	9000	8	365	1.77	4	0	3	BAS-CIN
MG178	AZ	WHITE MTS	HANNAGAN CR-PBAR TR						2651	8700	10	23	1.93	6	3	15	BASALT
MG 9	AZ	WHITE MTS	E FORK THOMAS CR						2758	9050	8	85	1.77	1	0	0	

TABLE C.2 (CONTINUED) -- SITE CHARACTERISTICS -- PICEA ENGELMANNII SERIES

PICEA ENGELMANNII/SENECIO CARDAMINE HT, ABIES CONCOLOR PH

HT NUMBER: 05 PHASE NUMBER: 02

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	(FT)	SLOPE (%)	ASPECT DEG	COS	LAND FORM	% COVER SOIL	ROCK	PARENT MATERIAL
MG543	NM	MOGOLLON MTS	BEARWALLOW PARK	BEARWALLOW MTN					2767	9080	25	294	0.64	4	0	15	BASALT
MG198	AZ	WHITE MTS	W FORK THOMAS CR						2636	8650	52	330	1.26	4	0	3	BASALT
MG256	AZ	WHITE MTS	BEAR CR TRIBUTARY						2682	8800	42	51	1.99	4	0	1	
MG182	AZ	WHITE MTS	E FORK THOMAS CR						2743	9000	5	45	2.00	1	T	T	BASALT
MG253	AZ	WHITE MTS	BEAR CR		3N	28E			2590	8500	46	291	0.59	4	0	3	
MG199	AZ	WHITE MTS	W FORK THOMAS CR						2621	8600	10	55	1.98	6	3	4	BASALT
MG 3	AZ	WHITE MOUNTAINS	E FORK THOMAS CR						2590	8500	6	10	1.82	6	5	13	BASALT
MG573	NM	MOGOLLON MTS	TURKEY CREEK	BEARWALLOW MTN					2865	9400	25	359	1.69	3	1	1	BASALT
MG183	AZ	WHITE MTS	E FORK THOMAS CR						2743	9000	13	51	1.99	12	0	0	BASALT
MG186	AZ	WHITE MTS	E FORK THOMAS CR						2712	8900	8	55	1.98	1	0	0	BASALT
MG190	AZ	WHITE MTS	RENO LO ROAD						2804	9200	15	198	0.11	2	0	0	BASALT
MG181	AZ	WHITE MTS	E FORK THOMAS CR						2743	9000	5	15	1.87	1	0	2	BASALT

PICEA ENGELMANNII/ACER GLABRUM HT

HT NUMBER: 06 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	(FT)	SLOPE (%)	ASPECT DEG	COS	LAND FORM	% COVER SOIL	ROCK	PARENT MATERIAL
ML209	NM	SACRAMENTO MTS	HUBBELL CANYON	ALAMOGORDO					2804	9200	40	5	1.77	4	0	0	
ML208	NM	SACRAMENTO MTS	SACRAMENTO RIV CAN	ALAMOGORDO					2712	8900	62	40	2.00	4	0	8	
MK406	AZ	CHIRICAHUA MTNS	CIMA CABIN	CHIRICAHUA PK					2773	9100	47	36	1.99	3	0	0	
DK 8	AZ	CHIRICAHUA MTNS	FLY PEAK	CHIRICAHUA PK.					2880	9450	30	5	1.77	3	0	T	RHYOLIT
DK 9	AZ	CHIRICAHUA MTNS	ROUND PARK	CHIRICAHUA PK.					2880	9450	32	55	1.98	3	T	T	RHYOLIT
DK 34	AZ	CHIRICAHUA MTNS	RASPBERRY RIDGE	CHIRICAHUA PK.					2804	9200	40	74	1.87	2	T	5	RHYOLIT

PICEA ENGELMANNII/ERIGERON EXIMIUS HT

HT NUMBER: 10 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	(FT)	SLOPE (%)	ASPECT DEG	COS	LAND FORM	% COVER SOIL	ROCK	PARENT MATERIAL
PLOT E	99 NOT FOUND																
MG540	NM	MOGOLLON MTS	QUAKING ASPEN CREEK	BEARWALLOW MTN					2755	9040	28	10	1.82	3	0	6	
MG577	NM	MOGOLLON MTS	1 MI S BEARWALLOW	BEARWALLOW MTN					2962	9720	28	56	1.98	2	0	3	BASALT
MG659	NM	BLACK RANGE	MIMBRES RIVER	REEDS PEAK					2697	8850	48	355	1.64	4	2	1	RHYOLIT
MG656	NM	BLACK RANGE	REEDS PEAK .4 MI N	REEDS PEAK					2962	9720	46	10	1.82	0	1	2	
MG 80	AZ	WHITE MOUNTAINS	BIG LAKE LOOKOUT						2758	9050	7	45	2.00	1	2	T	BASALT
MG 81	AZ	WHITE MOUNTAINS	BIG LAKE LOOKOUT						2749	9020	13	210	0.03	1	0	T	BASALT
MG262	AZ	WHITE MOUNTAINS	BURRO MOUNTAIN	BIG LAKE					2987	9800	16	196	0.13	3	T	T	
EW 94	AZ	WHITE MTS	RDY55 S FK SQUAW CK						2462	8080	20	320	1.09	4	T	T	BASALT

PICEA ENGELMANII/CAREX FOENEA HT

HT NUMBER: 09 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	(FT)	SLOPE (%)	ASPECT DEG	COS	LAND FORM	% COVER SOIL	ROCK	PARENT MATERIAL
MK400	AZ	PINALENO MTNS	PLAIN VIEW PEAK	MT. GRAHAM					3108	10200	42	194	0.14	3	20	6	GRANITE
MK401	AZ	PINALENO MTNS	PLAIN VIEW PEAK						3108	10200	25	173	0.38	12	0	0	

PICEA ENGELMANNII/ELYMUS TRITICOIDES HT

HT NUMBER: 07 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	(FT)	SLOPE (%)	ASPECT DEG	COS	LAND FORM	% COVER SOIL	ROCK	PARENT MATERIAL
ML236	NM	CAPITAN MTS	MITT-BAR TRAIL N060						0	0	35	66	1.93	12	0	35	
ML234	NM	CAPITAN MTS	FR56 .8MI PAST TR60						0	0	34	217	0.01	1	0	30	
ML232	NM	CAPITAN MTS	CAPITAN MTS						3017	9900	40	324	1.16	2	0	10	
ML231	NM	CAPITAN MTS	CAPITAN MTS						3017	9900	50	75	1.87	2	0	58	

TABLE C.2 (CONTINUED) -- SITE CHARACTERISTICS -- PICEA ENGELMANNII SERIES

PICEA ENGELMANNII/HERACLEUM SPONDYLIUM HT

HT NUMBER: 11 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	(FT)	SLOPE (%)	ASPECT DEG	COS	LAND FORM	% COVER SOIL	ROCK	PARENT MATERIAL
LN157	CO	NEEDLE MTNS	LIME CK CAMPGROUND	ENGINEER MT	39N	8W	4	SW	2761	9060	1	190	0.18	6	1	T	ALLUVIA
LN277	CO	SAN JUAN MTS	FISH CREEK	CHAMA PEAK					2712	8900	2	340	1.42	6	2	2	
LN 77	CO	SAN JUAN MTS	W FORK WOLF CK	WOLF CK PASS	37N	1W	7	SW	2502	8210	4	350	1.57	56	0	10	ALLUVIA

PICEA ENGELMANNII/SAXIFRAGA BRONCHIALIS HT

HT NUMBER: 08 PHASE NUMBER: 01

PLOT NO.	STATE	GEOGRAPHIC	LOCAL	USGS TOPOGRAPHIC QUADRANGLE	TWN	RNG	SEC	QTR	ELEVATION (M)	(FT)	SLOPE (%)	ASPECT DEG	COS	LAND FORM	% COVER SOIL	ROCK	PARENT MATERIAL
LN 91	CO	SAN MIGUEL MTNS	LITTLE FISH CK	GROUNDHOG MT	41N	12W	16	NW	3310	10860	55	159	0.59	3	10	68	GRN-QRT
LN100	CO	RICO MTNS	BARLOW LAKE TALUS	MT WILSON	40N	10W	9	NE	3041	9980	62	285	0.50	3	1	61	GRN-QRT
LN126	CO	LA PLATA MTNS	BARCO MT TALUS	LA PLATA	37N	11W	5	SW	3276	10750	2	350	1.57	3	0	84	GRANITE
LN128	CO	LA PLATA MTNS	SHRKTOOTH TRAIL HD	LA PLATA	37N	11W	20	NW	3337	10950	45	200	0.09	3	3	89	GRANITE
LN139	CO	LA PLATA MTNS	SLIDEROCK MT	MONUMENT HILL	36N	10W	2	NE	3200	10500	67	260	0.18	3	T	90	SANDSTN
LN196	CO	WET MTS	OPHIR CREEK	DEER PEAK					2980	9780	55	320	1.09	3	T	98	
LN228	CO	SANGRE RANGE	LAKE COMO	TWIN PEAKS					3596	11800	58	195	0.13	3	T	85	
LN235	CO	SANGRE RANGE	RASPBERRY CREEK	HOWARD					3093	10150	49	255	0.13	4	T	40	

Muldavin, Esteban; Ronco, Frank, Jr.; Aldon, Earl F. 1990. Consolidated stand tables and biodiversity data base for southwestern forest habitat types. Gen. Tech. Rep. RM-190. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 51 p.

To provide a foundation for future research into the biodiversity, structure, and dynamics of southwestern forest communities, stand tables consolidating over 2,000 field plots, stratified by 11 different climax forest tree series, have been compiled. The data upon which the tables are based are made available in a computerized format, accessible by microcomputer. A suite of computer programs is also provided for manipulating the data base to meet individual research needs.

Keywords: Habitat type, classification

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526